INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1890.

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PAST-PRESIDENTS.

George Stephenson, 1847-48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849-53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854-55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856-57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858-59, 1867-68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861-62, 1869.

Robert Napier, 1863-65. (*Deceased* 1876.)

John Ramsbottom, 1870-71.

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872-73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., F.R.S., 1874-75.

Thomas Hawksley, F.R.S., 1876-77.

John Robinson, 1878-79.

Edward A. Cowper, 1880-81.

Percy G. B. Westmacott, 1882-83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885-86.

Edward H. Carbutt, 1887-88.

Charles Cochrane, 1889.

OFFICERS.

1890.

PRESIDENT.

JOSEPH TOMLINSON, ... London.

PAST-PRESIDENTS.

THE RT. HON. LORD ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne.
SIR LOWTHIAN BELL, BART., F.R.S., ... Northallerton.
SIR FREDERICK J. BRAMWELL, BART., D.C.L., F.R.S., ... London.
EDWARD H. CARBUTT, ... London.
CHARLES COCHRANE, ... Stourbridge.
THOMAS HAWKSLEY, F.R.S., ... London.
JEREMIAH HEAD, ... Middlesbrough.
JOHN RAMSBOTTOM, ... Alderley Edge.
JOHN ROBINSON, ... Leek.
PERCY G. B. WESTMACOTT, ... Newcastle-on-Tyne.

VICE-PRESIDENTS.

WILLIAM ANDERSON, D.C.L., ... Woolwich.
SIR JAMES N. DOUGLASS, F.R.S., ... London.
ALEXANDER B. W. KENNEDY, F.R.S., ... London.
ARTHUR PAGET, ... Loughborough.
SIR JAMES RAMSDEN, ... Barrow-in-Furness.
E. WINDSOR RICHARDS, ... Low Moor.

MEMBERS OF COUNCIL.

BENJAMIN A. DOBSON, ... Bolton.
SIR DOUGLAS GALTON, K.C.B., D.C.L., F.R.S., ... London.
JOHN HOPKINSON, JUN., D.Sc., F.R.S., ... London.
SAMUEL W. JOHNSON, ... Derby.
WILLIAM LAIRD, ... Birkenhead.
JOHN G. MAIR-RUMLEY, ... London.
HENRY D. MARSHALL, ... Gainsborough.
EDWARD B. MARTEN, ... Stourbridge.
EDWARD P. MARTIN, ... Dowlais.
WILLIAM H. MAW, ... London.
T. HURRY RICHES, ... Cardiff.
BENJAMIN WALKER, ... Leeds.
WILLIAM H. WHITE, F.R.S., ... London.
J. HARTLEY WICKSTEED, ... Leeds.
THOMAS W. WORSDELL, ... Gateshead.

TREASURER.

HARRY LEE MILLAR.

SECRETARY.

ALFRED BACHE,

Institution of Mechanical Engineers, 19 *Victoria Street, Westminster, S.W.*

[Telegraphic address:—*Mech, London.*]

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Institution of Mechanical Engineers.

ESTABLISHED 1847.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

[*Telegraph Address and Telephone No. appended within brackets.*]

1890.

HONORARY LIFE MEMBERS.

1890. H. R. H. Albert Edward, Prince of Wales, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Marlborough House, Pall Mall, London, S.W.

1883. Abel, Sir Frederick Augustus, C.B., D.C.L., D.Sc., F.R.S., 1 Adam Street, London, W.C.; and 40 Cadogan Place, London, S.W.

1878. Crawford and Balcarres, The Right Hon. the Earl of, F.R.S., 2 Cavendish Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.

1889. Eiffel, Gustave, 37 Rue Pasquier, Paris.

1888. Haughton, Rev. Samuel, M.D., D.C.L., LL.D., F.R.S., Trinity College, Dublin.

1883. Kennedy, Professor Alexander Blackie William, F.R.S., 19 Little Queen Street, Westminster, S.W. [*Kinematic, London.*]

1878. Rayleigh, The Right Hon. Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.

1888. Rosse, The Right Hon. the Earl of, K.P., D.C.L., LL.D., F.R.S., Birr Castle, Parsonstown.

MEMBERS.

1890. Abbott, Arthur Harold, care of Messrs. Octavius Steel and Co., Calcutta, India: (or care of F. C. Abbott, 101 Lambeth Palace Road, London, S.E.)

1878. Abbott, Thomas, Newark Boiler Works, Newark. [*Abbott, Newark.*]

1883. Abbott, William Sutherland, Locomotive Superintendent and Assistant Engineer, Alagoas Railway, Maceio, Brazil: (or care of George S. Abbott, 9 Disraeli Road, Upton, London, E.)

1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C. [*Patentable, London.* 2729.]

1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.

1876. Adams, Henry, 60 Queen Victoria Street, London, E.C. [*Viburnum, London.*]

1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1848. Adams, William Alexander, Gaines, Worcester.

1881. Adams, William John, 35 Queen Victoria Street, London, E.C. [*Packing, London.* 1854.]

1859. Adamson, Daniel, Engineering Works, Dukinfield, near Manchester; and The Towers, Didsbury, Manchester.

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]

1886. Adamson, Thomas Alfred, 27 Leadenhall Street, London, E.C.

1878. Adcock, Francis Louis, care of I. B. Roscoe, Du Toit's pan Road, Kimberley, South Africa: (or care of William R. Adcock, 17 Rue Neuve de Berry, Havre, France.)

1851. Addison, John, Colehill Cottage, Fulham, London, S.W.

1889. Addy, George, Waverley Works, Effingham Road, Sheffield. [*Milling, Sheffield.*]

1887. Ahmed Bey, Colonel, Imperial Naval Arsenal, Constantinople.

1886. Aisbitt, Matthew Wheldon, 53 Mount Stuart Square, Cardiff. [*Aisbitt, Cardiff.*]

1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.

1886. Albright, John Francis, Messrs. R. E. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.; and Savernake Lodge, Chelmsford.

1885. Alderson, George Beeton, Messrs. Allen Alderson and Co., Alexandria, Egypt; The Lindens, Kew Road, R.O., Richmond, Surrey: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1881. Alexander, Edward Disney, Engineering Department, London County Council; and 9 Sheen Park, Richmond, Surrey.

1847. Allan, Alexander, Glen House, The Valley, Scarborough.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1885. Allcard, Harry, Messrs. Easterbrook Allcard and Co., Albert Works, Penistone Road, Sheffield.

1884. Allen, Alfred Evans, 37 Wellington Street, Hull.

1881. Allen, Percy Ruskin, Woodberrie Hill, Loughton, Essex.

1884. Allen, Samuel Wesley, 65 Bute Street, Bute Docks, Cardiff.

1885. Allen, William Henry, Messrs. W. H. Allen and Co., York Street Works, Lambeth, London, S.E. [*Pump, London.*]

1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1870. Alley, John, Malahova, Bekovo Station, Moscow and Riazan Railway, Moscow, Russia: (or care of W. Cuningham, Moscow.)

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, Messrs. Scriven and Co., Leeds Old Foundry, Marsh Lane, Leeds.

1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1876. Allport, Charles James, Whitehall Club, Parliament Street, Westminster, S.W.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

1884. Almond, Harry John, Cartagena and Herrerias Steam Tramways, 43 Muralla del Mar, Cartagena, Spain: (or care of Messrs. G. and W. Almond, 67 Willow Walk, London, S.E.)

1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.

1876. Anderson, Henry John Card, 13 Mount Ararat Road, Richmond, Surrey.

1890. Anderson, Herbert William, Messrs. Hilton Anderson and Co., Manor Works, Halling, near Rochester.

1884. Anderson, Samuel, Westbury Iron Works, Westbury, Wiltshire.

1856. Anderson, William, D.C.L., Director-General of Ordnance Factories, Royal Arsenal, Woolwich; and Lesney House, Erith, S. O., Kent.

1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.

1867. Appleby, Charles James, Messrs. Appleby Brothers, 22 Walbrook, London, E.C. [*Millwright, London.*]; and East Greenwich Works, London, S.E.

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1881. Archbold, Joseph Gibson, Manager, Blyth Dry Dock, Blyth, Northumberland.

1889. Archer, Charles Frederick, Messrs. Joseph Richmond and Co., 30 Kirby Street, Hatton Garden, London, E.C.

1874. Archer, David, Oldbury Railway-Carriage and Wagon Co., Oldbury, near Birmingham; and 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.; and 13 Clifton Road, Brockley, London, S.E.

1887. Armit, Thomas Napier, Dundee Salvage Co., 23 Panmure Street, Dundee. [*Armit, Dundee.*]

1859. Armitage, William James, Farnley Iron Works, Leeds.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, F.R.S.E., Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1858. Armstrong, The Right Hon. Lord, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Messrs. Willans Arnold and Co., Spanish Steel Works, Sheffield.

1879. Arrol, Thomas Arthur, Messrs. Arrol Brothers, Germiston Iron Works, Glasgow; and 18 Blythswood Square, Glasgow. [*Germiston, Glasgow.* 1080.]

1887. Arrol, Sir William, Dalmarnock Iron Works, Glasgow.

1887. Arteaga, Alberto de, 331½ Buen Orden, Buenos Aires, Argentine Republic: (or care of M. Raggio-Carneiro, 129A Winchester House, Old Broad Street, London, E.C.)

1873. Ashbury, Thomas (*Life Member*), 5 Market Street, Manchester; and Ash Grove, Victoria Park, Longsight, Manchester. [*Thomas Ashbury, Manchester.*]

1888. Ashby, George, Tardeo, Bombay, India.

1890. Ashley, Thomas James, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool.

1884. Ashwell, Frank, Victoria Foundry, Sycamore Lane, Leicester. [*Iron, Leicester.* 100.]

1890. Askham, John Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1890. Askham, Philip Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1881. Aspinall, John Audley Frederick, Chief Mechanical Engineer, Lancashire and Yorkshire Railway, Horwich, near Bolton; and Fern Bank, Heaton, Bolton.

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1890. Aston, John W., Chief Teacher of Mechanical Science, Municipal School of Art, Birmingham; and Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham.

1889. Atkinson, Alexander, Engineer to H.H. the Maharajah of Kashmir, Kashmir, viâ Murree, Punjaub, India: 54 Eardley Crescent, Earl's Court, London, S.W.: (or care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.)

1875. Atkinson, Edward (*Life Member*), The Projectile Company, New Road, Wandsworth Road, London, S.W.

1890. Atkinson, Edward Turner, London County Council, Spring Gardens, London, S.W.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester. [*Aveling, Rochester.*]

1890. Bailey, Charles Stuart, Messrs. Bailey Nokes and Co., 35 Royal Exchange, London, E.C.

1886. Bailey, William, 14 Delahay Street, Westminster, S.W.

1885. Bailey, William Henry, Albion Works, Salford, Manchester. [*Beacon, Salford.*]

1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1887. Baillie, Robert Alexander, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1872. Bailly, Philimond, 282 Rue Royale, Bruxelles, Belgium.

1890. Bain, George, Locomotive Department, Egyptian Government Railways, Cairo, Egypt.

1880. Bain, William Neish, Messrs. Kyle and Bain, Hong Kong Ice Works, Eastpoint, Hong Kong, China; 22 St. Enoch Square, Glasgow; and Collingwood, 7 Aytoun Road, Pollokshields, Glasgow. [*Glacis, Glasgow.*]

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1873. Baird, George, St. Petersburg; and Fulmer, Slough.
1890. Baker, Sir Benjamin, K.C.M.G. (*Life Member*), 2 Queen Square Place, Westminster, S.W.
1887. Baker, William James, 2 New Street, Huddersfield. [*Patent, Huddersfield.*]
1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.
1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.
1884. Balmokand, Lala, Executive Engineer, Public Works Department, Punjaub, India; care of Lala Shamba Das, Said Mitha, Lahore, India.
1887. Bamlett, Adam Carlisle, Agricultural Engineering Works, Thirsk.
1879. Banderali, David, Assistant Locomotive and Carriage Superintendent, Chemin de fer du Nord, Paris.
1888. Baraclough, William Henry, Great Western Buildings, 6 Livery Street, Birmingham.
1885. Barker, Tom Birkett, Scholefield Street, Birmingham.
1882. Barlow, Henry Bernoulli, 4 Mansfield Chambers, 17 St. Ann's Square, Manchester. [*Monopoly, Manchester.*]
1880. Barlow-Massicks, Thomas, Millom Iron Works, Millom, Cumberland.
1881. Barnett, John Davis, Mechanical Superintendent, Grand Trunk Railway, Stratford, Ontario, Canada.
1887. Barningham, James, 27 Corporation Street, Manchester.
1884. Barr, Archibald, D.Sc., Professor of Engineering, The University, Glasgow.
1878. Barr, James, care of William McConnell, Underwood House, Paisley.
1883. Barras, Harry Haywood, 7 Howard Street, Rotherham; and Broom Lodge, Rotherham.
1879. Barratt, Samuel, Engineer and Manager, Corporation Gas Works, Rochdale Road Station, Manchester.
1882. Barrett, John James, 5 Chinchpoogly Road, Bombay, India; and Nawab's Bungalow, Mazagon, Bombay, India.
1885. Barrie, William, Superintendent Engineer, Nippon Yusen Kaisha Steam Ship Co., Yokohama, Japan.
1887. Barringer, Herbert, Assistant Superintendent Engineer, Messrs. Scrutton Sons and Co., 9 Gracechurch Street, London, E.C.
1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]
1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury. [*Barrows, Banbury.*]
1871. Barry, John Wolfe, 21 Delahay Street, Westminster, S.W. [*Wolfebarry, London.* 3024.]
1883. Bartlett, James Herbert, Standard Building, Montreal, Canada; and 37 Old Jewry, London, E.C.
1887. Bate, Capt. Charles McGuire, R.E., War Office, Whitehall, London, S.W.

1885. Bateman, Henry, Superintending Engineer, Rangoon Tramways, Rangoon, India.

1889. Bayford, William James, Engineer, Messrs. Meakin and Co., Brewers, Delhi, India.

1872. Bayliss, Thomas Richard, Belmont, Northfield, Birmingham.

1877. Beale, William Phipson, 12 Old Square, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1887. Beardmore, William, Parkhead Forge and Steel Works, Glasgow.

1880. Beaumont, William Worby, 163 Strand, London, W.C.; and Melford, Palace Road, Tulse Hill, London, S.W.

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and Springfield, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

1887. Beckwith, George, Enfield House, Fairlop Road, Leytonstone, London, N.E.

1875. Beckwith, John Henry, Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Messrs. Richard Johnson and Nephew, Bradford Iron Works, Manchester.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester. [*Beeley, Hyde.*]

1884. Beetlestone, George John, Sudbrook Works, near Chepstow.

1888. Beldam, Asplan, 77 Gracechurch Street, London, E.C.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough.

1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; and Reform Club, Pall Mall, London, S.W. [*Sir Lowthian Bell, Middlesbrough.*]

1880. Bell, William Henry, Vale Rectory, Guernsey.

1879. Bellamy, Charles James, 5 Priory Gardens, Bedford Park, London, W.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham. [*Belliss, Birmingham.*]

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W [*Benham, London.* 7065.]

1887. Bennetts, Edward John, Battery Reef Gold Mine, P.O. Box 96, Krugersdorp, Transvaal, South Africa.

1890. Berkley, James Eustace, Locomotive and Carriage Superintendent, H.H. the Nizam's Guaranteed State Railways, Secunderabad, India.

1878. Berrier-Fontaine, Marc, Directeur des Constructions navales, Rochefort-sur-mer, Charente-inférieure, France: (or care of Messrs. P. S. King and Son, Canada Buildings, King Street, Westminster, S.W.) [*Berrier, Rochefort-sur-mer.*]

1890. Bertram, Alexander, Wigan Coal and Iron Works, Wigan.

1887. Bertram, William, Messrs. George and William Bertram, St. Katherine's Works, Sciennes, Edinburgh.

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1885. Bicknell, Arthur Channing, 42 Pelham Street, South Kensington, London, S.W.

1883. Bicknell, Edward, care of Bank of Bengal, Calcutta, India: (or 8 Canynge Square, Clifton, Bristol).

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles, Belgium.

1888. Billinton, Robert John, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.

1890. Bingham, Charles Henry, Messrs. Walker and Hall, Electro Works, Sheffield.

1887. Binnie, Alexander Richardson, Engineer, London County Council, Spring Gardens, London, S.W.; and 14 Campden Hill Gardens, Notting Hill, London, W.

1877. Birch, Robert William Peregrine, 5 Queen Anne's Gate, Westminster, S.W.

1847. Birley, Henry, 6 Brentwood, Pendleton, R.O., Manchester.

1888. Birtwistle, Richard, Messrs. S. S. Stott and Co., Lancside Foundry, Haslingden, Manchester.

1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead. [*Blackthorn, Newcastletyne.*]

1890. Blackburn, John, Resident Engineer, Colne Valley Water Works, Bushey, Watford.

1890. Blair, Peter Borrie, Messrs. Blair and Co., Stockton-on-Tees.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1886. Blandford, Thomas, Corbridge, R.S.O., Northumberland.

1881. Blechynden, Alfred, Naval Construction and Armaments Works, Barrow-in-Furness.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1882. Blundstone, Samuel Richardson, Catherine Chambers, 8 Catherine Street, Strand, London, W.C.

1863. Boedlinghaus, Julius, Electrotechniker, Düsseldorf, Germany.

1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.

1890. Booth, Robert, 110 Cannon Street, London, E.C.

1883. Booth, William Stanway, Messrs. Vivian and Sons, Hafod Foundry, Swansea.

1880. Borodin, Alexander, Engineer-in-Chief, Russian South Western Railways, Kieff, Russia.

1888. Borrows, William. Messrs. Edward Borrows and Sons, Providence Foundry, Sutton, St. Helen's, Lancashire.

1885. Boughton, Henry Francis, Dan Rylands, Glass Works, Barnsley; and Hunningley, near Barnsley.

1886. Boult, Alfred Julius, Messrs. W. P. Thompson and Boult, 323 High Holborn, London, W.C.

1888. Boultbee, Frederic Richard, 4 Loris Road, Shepherd's Bush, London, W.

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1879. Bovey, Henry Taylor, Professor of Engineering, McGill University, Montreal, Canada.

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. Bowen, Edward (*Life Member*), Locomotive and Carriage Superintendent, Porto Alegre and New Hamburg Railway, Rio Grande do Sol, Brazil: (or care of Benjamin Packham, 122 Upper Lewes Road, Brighton.)

1870. Bower, Anthony, Gayton Cottage, Heswall, near Chester.

1858. Bower, John Wilkes (*Life Member*), Neston, near Chester.

1890. Boyd, John White, Superintendent Engineer, Hong Kong and Whampoa Dock Co., Hong Kong, China.

1884. Boyer, Robert Skeffington, Merchants' Exchange, Pier Head, Cardiff.

1882. Bradley, Frederic, Wolverley House, Southport.

1889. Bradley, Isaac, Manager, Gatling Gun Works, Perry Barr, Birmingham.

1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.

1875. Braithwaite, Richard Charles, Messrs. Braithwaite and Kirk, Crown Bridge Works, Westbromwich; and Norfolk House, Handsworth, R. O., Birmingham. [*Braithwaite, Westbromwich.*]

1854. Bramwell, Sir Frederick Joseph, Bart., D.C.L., F.R.S., 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1888. Bratt, Augustus Hicks Henery, Mechanical Engineer, New Prye River Dock, Province Wellesley, Straits Settlements: (or Sunnyside, Old Trafford, Manchester.)

1885. Brearley, Benjamin J., Union Plate Glass Works, St. Helen's.

1889. Brebner, Samuel Gordon, Chief Mechanical Engineer, Small Arms Ammunition Factory, Poona, India.

1868. Breeden, Joseph, New Mill Works, Fazeley Street, Birmingham. [*Breeden, Birmingham.*]

1890. Brewster, Walter Seckford, Messrs. Beyer Peacock and Co.; Halstead Lodge, Ocean Street, Woollahra, Sydney, New South Wales.

1883. Bricknell, Augustus Lea, 56 Arlington Road, Brixton, London, S.W.

1887. Brier, Henry, Scotch and Irish Oxygen Co., Rosehill Works, Polmadie, Glasgow.

1889. Briggs, Charles, Jun., Superintendent of Machinery, Companhia do Beberibe, Pernambuco, Brazil: (or care of Robert Briggs, Howden.)

1881. Briggs, John Henry, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and Howden.

1889. Bright, Philip, Messrs. J. Tylor and Sons, 2 Newgate Street, London, E.C.

1886. Bright, William, Manager, Fairwood Tin-Plate Works, Gowerton, R.S.O., Glamorganshire.

1865. Brock, Walter, Messrs. Denny and Brothers, Engine Works, Dumbarton.

1890. Brodie, John Alexander, City Engineer's Office, Liverpool.

1879. Brodie, John Shanks, Town Surveyor and Harbour Engineer, Town Hall, Whitehaven.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1890. Brogden, Thomas, Messrs. Appleby and Brogden, Sandside, Scarborough.

1884. Brook-Fox, Frederick George, Executive Engineer, South Indian Railway, Vellore, Madras Presidency, India: (or care of Messrs. H. S. King and Co., 65 Cornhill, London, E.C.)

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 94 Cromwell Road, South Kensington, London, S.W. [*Brotherhood, London.*]

1886. Brown, Andrew, Messrs. T. Cosser and Co., McLeod Road Iron Works, Kurrachee, India: (or care of P. B. Brown, Hecla Works, Sheffield.)

1866. Brown, Andrew Betts, F.R.S.E., Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1879. Brown, Charles, Messrs. Charles Brown and Co., 91 Rione Amedeo, Naples, Italy: [*Brown Comp., Naples.*] (or care of Dr. Gardiner Brown, 9 St. Thomas' Street, London Bridge, London, S.E.)

1880. Brown, Francis Robert Fountaine, Superintendent, Dominion Bridge Co., Lachine Locks, P.Q., Canada.

1889. Brown, Frederick Alexander William, Royal Laboratory, Royal Arsenal, Woolwich; and 199 Eglinton Road, Plumstead.

1888. Brown, Frederick Gills, Messrs. Brown and David, Australian Chambers, Queen Street, Brisbane, Queensland; and care of Commissioner, Australian Irrigation Colonies, 35 Queen Victoria Street, London, E.C.

1881. Brown, George William, Messrs. Huntley Boorne and Stevens, Reading Tin Works, Reading.

1863. Brown, Henry, Aldridge Road, Perry Barr, Birmingham.

1887. Brown, James, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne.

1884. Brown, Oswald, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W. [*Acqua, London.*]

1890. Brown, Robert, 51 Waterloo, Northampton.

1888. Brown, William, Messrs. W. Simons and Co., London Works, Renfrew.

1887. Browne, Frederick John, Tay Creggan, Ealing Dean, London, W.

1874. Browne, Tomyns Reginald, Deputy Locomotive Superintendent, East Indian Railway, Jamalpur, Bengal, India: (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.)

1874. Bruce, Sir George Barclay, 2 Westminster Chambers, 3 Victoria Street, Westminster, S.W.

1889. Bruce, Robert, 30 Great St. Helen's, London, E.C.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta; and 23 Roland Gardens, South Kensington, London, S.W.

1888. Bruff, Charles Clarke, Coalport China Co., Coalport, near Ironbridge, Salop.

1873. Brunel, Henry Marc, 21 Delahay Street, Westminster, S.W. [3024.]

1870. Brunlees, Sir James, F.R.S.E., 12 Victoria Street, Westminster, S.W.

1887. Brunton, Philip George, Resident Engineer, Department of Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of J. D. Brunton, 19 Great George Street, Westminster, S.W.)

1884. Bryan, William B., Engineer, East London Water Works, Old Ford, London, E.

1888. Bryce-Douglas, Archibald Douglas, Naval Construction and Armaments Works, Barrow-in-Furness.

1873. Buckley, Robert Burton, Superintending Engineer, East Indian Railway, Arrah, Bengal, India: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1886. Buckney, Thomas, Messrs. E. Dent and Co., 61 Strand, London, W.C.

1887. Buckton, Walter, 27 Ladbroke Square, London, W.

1878. Buddicom, Harry William, Plas-Derwen, Abergavenny.

1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester. [*Manometer, Manchester.* 899.]

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile: (or care of Messrs. Rose-Innes and Co., 90 Cannon Street, London, E.C.)

1881. Bulkley, Henry Wheeler, 149 Broadway, New York.

1884. Bullock, Joseph Henry, General Manager, Pelsall Coal and Iron Works, near Walsall.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1884. Bunning, Charles Ziethen, The Borax Co., 2 Macri Khan, Constantinople.

1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)

1884. Bunting, George Albert, Locomotive Superintendent, Costa Rica Railways; Gaisford House. Gaisford Street, Kentish Town, London, N.W.

1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1878. Burnett, Robert Harvey, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1885. Burrell, Frederick John, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1887. Burstal, Edward Kynaston, Messrs. Stevenson and Burstal, 38 Parliament Street, Westminster, S.W.

1890. Burstall, Henry Robert John, 19 Little Queen Street, Westminster, S.W.; and 76 King's Road, London, N.W.

1877. Burton, Clerke, 22 Oakfield Street. Roath, Cardiff.

1882. Butler, Edmund, Kirkstall Forge, near Leeds. [*Forge, Kirkstall.*]

1888. Butter, Frederick Henry, Carriage Department, Royal Arsenal, Woolwich; and 4 Hanover Road, Brookhill Park, Plumstead.

1887. Caiger, Emery John, Messrs. W. J. Helmore and Co., 51 Lime Street, London, E.C.

1889. Callan, William, River Plate Fresh Meat Co., 2 Coleman Street, London, E.C.

1886. Cambridge, Henry, Stuart Chambers, Mount Stuart Square, Cardiff.

1877. Campbell, Angus, Logie, Mussoorie, N. W. Provinces, India.

1880. Campbell, Daniel, Messrs. Campbell and Schultz, 90 Cannon Street, London, E.C. [*Duke, London.* 1893.]

1869. Campbell, James, Hunslet Engine Works, Leeds. [*Engineco, Leeds.*]

1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java: (or care of R. Campbell, Slamat Cottage, Mount Vernon, Glasgow.)

1885. Capito, Charles Alfred Adolph, 12 Prince's Street, Hanover Square, London, W.; and 9 Belgrave Terrace, Lee, London, S.E.

1860. Carbutt, Edward Hamer, 19 Hyde Park Gardens, London, W.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, Burma State Railways Inscin, Burma; care of Messrs. King King and Co., Bombay, India: (or care of Rev. J. H. Cardew, Wingfield Rectory, Trowbridge.)

1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmão, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1878. Carlton, Thomas William, Messrs. Taite and Carlton, 63 Queen Victoria Street, London. E.C. [1618.]; and 1 Canfield Gardens, Priory Road, West Hampstead, London, N.W.

1887. Carlyle, Thomas, Inspector of Ordnance Machinery, Royal Artillery, Singapore: (or 72 Glyndon Road, Plumstead.)

1869. Carpmael, Frederick, 106 Croxted Road, West Dulwich, London, S.E.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C. [*Carpmael, London.* 2608.]

1877. Carr, Robert, Chief Engineer, London and India Docks Joint Committee, Dock House, 109 Leadenhall Street, London, E.C.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Holly House, Gateshead. [*Wardale, Gateshead.*]

1888. Carrick, Samuel Stewart, Superintendent Engineer, Shaw Savill and Albion Steamship Co., 34 Leadenhall Street, London, E.C.

1874. Carrington, William T. H., 72 Mark Lane, London, E.C.

1877. Carter, Claude, Manager, Messrs. Hetherington and Co., Ancoats Works, Pollard Street, Manchester.

1885. Carter, Herbert Fuller, La Compañia Unida, Guanajuato, Mexico: (or care of H. M. Carter, 1 Gresham Buildings, Basinghall Street, London, E.C.)

1877. Carter, William, Manager, The Hydraulic Engineering Company, Chester.

1890. Carver, Henry Clifton, Messrs. Coates and Carver, 3 Cross Street, Manchester.

1888. Castle, Frank, Normal School of Science, South Kensington, London, S.W.

1883. Cawley, George, 358 Strand, London, W.C.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1886. Chalmers, John Reid, 18 Hemingford Road, Barnsbury, London, N.

1884. Chamberlain, John, Charters Towers Gas Works, Charters Towers, Queensland: (or care of J. Chamberlain, 188 West Ferry Road, Millwall, Poplar, London, E.)

1890. Chandler, Noel, Cannock Chase Foundry and Engine Works, Hednesford, near Stafford.

1887. Chapman, Alfred Crawhall, 2 St. Nicholas' Buildings, Newcastle-on-Tyne.

1888. Chapman, Arthur, Messrs. Marillier and Edwards, 1 Hastings Street, Calcutta, India.

1882. Chapman, Hedley, Messrs. Chapman Carverhill and Co., Scotswood Road, Newcastle-on-Tyne.

1866. Chapman, Henry, 69 Victoria Street, Westminster, S.W. [*Tubalcain, London.*]; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]

1885. Chapman, John, Engineer and Manager, Windsor Corporation Water Works, Tangier Islands, Eton.

1887. Chapman, Joseph Crawhall, 70 Chancery Lane, London, W.C.

1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1890. Chater, John Richard, Madras Railway, Madras, India.

1887. Chatwin, James, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and Irwell House, Drinkwater Park, Prestwich, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, The Terrace, H.M. Dockyard, Sheerness.

1877. Chisholm, John, Messrs. William Muir and Co., Sherborne Street, Manchester; and 30 Devonshire Street, Higher Broughton, Manchester.

1886. Chittenden, Edmund Barrow, Messrs. Chittenden Knight and Co., Sittingbourne; and Manor House, Offham, West Malling, near Maidstone.

1888. Chubb, Thomas Lyon, Ferro Carril del Sud, Buenos Aires, Argentine Republic.

1880. Churchward, George Dundas, Locomotive Superintendent, China Railway Company, care of H.B.M.'s Consulate, Tientsin, North China: (or care of A. W. Churchward, London Chatham and Dover Railway, Queenborough Pier, Queenborough.)

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan. [*Park Lane, Wigan.*]

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1867. Clark, George, Southwick Engine Works, near Sunderland.

1889. Clark, Thomas Alexander, Superintendent of Workshops, George Heriot's Hospital School, Edinburgh.

1889. Clarke, Francis, Dane John Iron Works, Canterbury.

1865. Clarke, John, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1885. Clarke, Leslie, 132 Westbourne Terrace, Hyde Park, London, W.

1869. Clarke, William, Messrs. Clarke Chapman and Gurney, Victoria Works, South Shore, Gateshead.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln. [*Claytons, Lincoln.*]

1886. Clayton, Samuel, St. Thomas' Engine Works, Sunbridge Road, Bradford.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1890. Cleathero, Edward Thomas, Messrs. Cleathero and Nichols, Phœnix Works, Boleyn Road, Kingsland, London, N.; and 16 Tollington Place, London, N.

1890. Cleaver, Arthur, Engineer, Nottingham Laundry Co., Sherwood, near Nottingham; and Hornby House, Sherwood, near Nottingham.

1890. Cleland, William, Sheffield Testing Works, Blonk Street, Sheffield.

1871. Cleminson, James, Dashwood House, 9 New Broad Street, London, E.C. [*Catamarca, London.*]

1873. Clench, Frederick, Messrs. Robey and Co., Globe Iron Works, Lincoln. [*Robey, Lincoln.*]

1885. Clifton, George Bellamy, Great Western Railway Electric Light Works, 150 Westbourne Terrace, Paddington, London, W.

1885. Close, John, Jun., York Engineering Works, Leeman Road, York.

1885. Clutterbuck, Herbert, Temple Villa, Burton Road, Derby.

1882. Coates, Joseph, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1883. Coath, David Decimus, Agricultural Implement Works and Saw Mill, Rangoon, British Burmah, India.

1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and Green Royde, Pedmore, near Stourbridge.

1887. Cochrane, George, Resident Engineer, London Hydraulic Power Works, 46 Holland Street, Blackfriars Road, London, S.E.

1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow. [*Cochrane, Barrhead.*]

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1864. Coddington, William, M.P., Ordnance Cotton Mill, Blackburn; and Wycollar, Blackburn.

1889. Coey, Robert, Assistant Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1889. Colam, William Newby, Engineer, Cable Tramways, Henderson Row, Edinburgh.

1884. Cole, Charles, Messrs. Cole Booth and Co., Vulcan Works, Dudley Hill, Bradford.

1878. Cole, John William, Messrs. James Martin and Co., Phœnix Foundry. Gawler, South Australia: (or care of J. C. Lanyon, 27 Gresham House, Old Broad Street, London, E.C.)

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.

1877. Coley, Henry, Mansion House Chambers, Queen Victoria Street, London, E.C.

1884. Collenette, Ralph, 38 Dixon Street, Rotherham.

1884. Colquhoun, James, General Manager, Tredegar Iron Coal and Steel Works, Tredegar.

1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.

1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.

1888. Combe, Abram, Messrs. Combe Barbour and Combe, Falls Foundry, Belfast.

1889. Common, John Freeland Fergus, 4 Bute Crescent, Cardiff.

1881. Compton-Bracebridge, John Edward, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1888. Constantine, Ezekiel Grayson, 32 Victoria Street, Manchester. [*Constant, Manchester.*]

1874. Conyers, William, Engineer, New Zealand Pine Works, Invercargill, New Zealand.

1888. Cook, John Joseph, Messrs. Robinson Cooks and Co., Atlas Foundry, St. Helen's, Lancashire.

1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.

1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, Telegraph Works, Pownall Road, Dalston, London, E. [*Patella, London.* 1140.]

1877. Cooper, George, Pencliffe, Alleyne Road, West Dulwich, London, S.E.

1874. Cooper, William, Neptune Engine Works, Hull. [*Neptune, Hull.*]

1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne.

1881. Copeland, Charles John, Messrs. Westray Copeland and Co., Barrow-in-Furness. [*Engine, Barrow-in-Furness.*]

1885. Coppée, Evence, 223 Avenue Louise, Bruxelles, Belgium.

1884. Corder, George Alexander, 74 Ivydale Road, Nunhead, London, S.E.

1878. Cornes, Cornelius, 6 Norfolk Crescent, Bath, [*Stothert, Cornes, Bath.*]; and 76 Cannon Street, London, E.C. [*Stothert, Cornes, London.*]

1848. Corry, Edward, 9 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India: (or care of Messrs. Ironside Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.)

1884. Cotton, John, Messrs. E. Ripley and Sons, Bowling Dye Works, Bradford.

1875. Cottrill, Robert Nivin, Beehive Works, Bolton. [*Beehive, Bolton.*]

1887. Coulman, John, Hull and Barnsley Railway, Spring Head Works, Hull.

1868. Coulson, William, 1 Pimlico, Durham.

1878. Courtney, Frank Stuart, 3 Whitehall Place, London, S.W.; and 76 Redcliffe Square, South Kensington, London, S.W.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham; and 9 The Ropewalk, Nottingham. [*Cowen, Nottingham.* 87.]

1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1887. Crabbe, Alexander, 4 Hawkhill Place, Dundee.

1883. Crampton, George, care of T. Hillas Crampton, 100 Eaton Place, London, S.W.

1882. Craven, John, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1890. Craven, Thomas Edwin, 24 Victoria Chambers, South Parade, Leeds.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1889. Cribb, Frederick James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1884. Crighton, John, Union Engineering Co., 2 Clarence Buildings, Booth Street, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1883. Croft, Henry, Chemainus, Vancouver Island.

1878. Crohn, Frederick William, 16 Burney Street, Greenwich, London, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C. [*Crompton, Chelmsford.*]

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

1881. Crosland, James Foyell Lovelock, Chief Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Eirianfa, Llangollen.

1890. Cross, Robert James, Consulting Engineer, Great Western Steamship Co.; care of Messrs. Mark Whitwill and Son, Bristol.

1871. Crossley, William, 153 Queen Street, Glasgow. [*Crossley, Glasgow.* 584.]

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester. [*Crossleys, Openshaw.*]

1888. Crowe, George, Albion Chambers, Bute Docks, Cardiff.

1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.

1886. Cryer, Thomas, Mechanical Engineering Department, Manchester Technical School, Princess Street, Manchester; and Urmston, near Manchester.

1889. Cullen, William Hart, Resident Engineer, The Aluminium Co., Oldbury, near Birmingham.

1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester. [*Curtius, Manchester.*]

1887. Cutler, George Benjamin, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. ; and 4 Westcombe Park, Blackheath, London, S.E.

1876. Cutler, Samuel, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* 5059.]; and 16 Great George Street, Westminster, S.W.

1888. Dadabhoy, Cursetjee, Messrs. Shapurji Sorabji and Co., Bombay Foundry and Engine Works, Khetwady, Bombay, India; and Cumbala Hill, Bombay, India.

1864. Daglish, George Heaton, Rock Mount, St. Anne's Road, Aigburth, near Liverpool. [*Daglish, Aigburth.* 2717.]

1883. D'Albert, Charles, Messrs. Hotchkiss and Co., 6 Route de Gonesse, St. Denis, near Paris; and 16 Rue des Chesneaux, Montmorency, Seine-et-Oise, France.

1890. Dalby, William Ernest, Permanent-Way Stores Department, London and North Western Railway, Crewe.

1889. Dalgarno, James Robert, Danesford, Countess Wells Road, Mannofield, Aberdeen.

1881. D'Alton, Patrick Walter, London Electric Supply Corporation, Stowage Wharf, Deptford, London, S.E.

1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Fern Bank, Horsforth, Leeds.

1888. Darbishire, James Edward, 110 Cannon Street, London, E.C.

1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds [*Sun Foundry, Leeds*]; and 3 Prince's Street, Westminster, S.W.

1884. Davidson, James Young, 13 Fairlawn Avenue, Acton Green, Chiswick, London, W.

1888. Davidson, Samuel Cleland, Sirocco Works, Bridge End, Belfast.

1884. Davies, Alfred Herbert, Eskell Chambers, Market Place, Nottingham.

1880. Davies, Charles Merson, Locomotive Carriage and Wagon Superintendent, Bengal-Nagpur Railway, Nagpur, Central Provinces, India.

1885. Davies, Edward John Mines, 24 Harrington Square, London, N.W.

1874. Davis, Alfred, 2 St. Ermin's Mansions, Westminster, S.W. [*Sivad, London.*]

1868. Davis, Henry Wheeler, 53 New Broad Street, London, E.C.

1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 1 Arthur Street West, London, E.C.

1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.

1877. Davison, John Walter, care of W. G. P. Joyner, Pirie Chambers, Pirie Street, Adelaide, South Australia: (or care of Alfred L. Sacré, 60 Queen Victoria Street, London, E.C.)

1884. Davison, Robert, Caledonian Railway, Locomotive Department, St. Rollox, Glasgow.

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield. [*Motor, Sheffield.*]

1883. Daw, James Gilbert, Messrs. Nevill Druce and Co., Llanelly Copper Works, Llanelly.

1874. Daw, Samuel, Staffa Lodge, South Park Hill Road, Croydon.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London.*]; and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1875. Dawson, Edward, Messrs. Forster Brown and Rees, Guild Hall Chambers, Cardiff.

1890. Day, George Cameron, Messrs. Day Summers and Co., Northam Iron Works, Southampton.

1869. Day, St. John Vincent, F.R.S.E., Cawder House, Bishopbriggs, near Glasgow.

1886. Dayson, William Ogden, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1874. Deacon, George Frederick, Victoria Mansions, 32 Victoria Street, Westminster, S.W.; and 1 Whitehall Gardens, London, S.W.

1880. Deacon, Richard William, Messrs. Samuel Fisher and Co., Nile Foundry, Birmingham; and 19 Clarendon Road, Edgbaston, Birmingham.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.

1887. Deas, James, Clyde Navigation, Glasgow.

1866 Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1884. Decauville, Paul, Portable Railway Works, Petit Bourg, Seine et Oise, France. [*Decauville, Corbeil.*]

1890. Deeley, Richard Mountford, Locomotive Department, Midland Railway, Derby; and 10 Charnwood Street, Derby.

1877. Dees, James Gibson, 36 King Street, Whitehaven.

1889. Defries, Wolf, Messrs. Defries and Sons, 147 Houndsditch, London, E. [*Defries, London.*]

1858. Dempsey, William, 26 Great George Street, Westminster, S.W.

1882. Denison, Samuel, Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds. [*Weigh, Leeds.* 221.]

1888. Dent, Charles Hastings, Locomotive Department, London and North Western Railway, Preston.

1883. Dick, Frank Wesley, Newton Steel Works, near Glasgow.

1890. Dickinson, Alfred, Engineer, South Staffordshire Tramways, Darlaston, Wednesbury.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]

1875. Dickinson, William, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1888. Dickson, George Manners, Assistant Engineer, Calcutta Water Works, Municipal Office, Calcutta, India.

1886. Dixon, Robert, Messrs. Dixon and Corbitt, Teams Hemp and Wire Rope Works, Gateshead. [*Dixon, Gateshead.*]

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.*]

1887. Dixon, William Basil, Earle's Shipbuilding and Engineering Works, Hull.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1873. Dobson, Richard Joseph Caistor, Suiker Fabriek, Kalibayor, Banjoemas, Java: (or care of Charles E. S. Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]

1889. Dolby, Ernest Richard, 8 Prince's Street, Westminster, S.W.

1880. Donald, James, care of J. Macfarlane Gray, St. Katharine Dock House, Tower Hill, London, E.

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Southwark Park Road, Bermondsey, London, S.E.

1884. Donnelly, John, 45 Brockley Road, London, S.E.

1865. Douglas, Charles Prattman, Consett Iron Works, near Blackhill, County Durham; and Parliament Street, Consett, County Durham.

1879. Douglass, Sir James Nicholas, F.R.S., Trinity House, London, E.C. [2242.]; and Stella House, Dulwich, London, S.E.

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1887. Douglass, William Tregarthen, 59 Kenninghall Road, Upper Clapton, London, N.E.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster [*Redbourn, Frodingham.*]; and Hatfield House, Hatfield, near Doncaster.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.

1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W. [*Gaseous, London.*]

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C. [3663.]

1890. Drewet, Tom, Government Senior Inspector of Steam Boilers, Town Custom House, Bombay, India.

1886. Drummond, Dugald, Locomotive Superintendent, Caledonian Railway, St. Rollox Works, Glasgow.

1889. Drummond, Richard Oliver Gardner, De Beer's Diamond Mining Co., Kimberley, South Africa.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1881. Duckham, Heber, 184 Lewisham Road, London, S.E. [*Duckham, London.*]

1879. Duncan, David John Russell, Messrs. Duncan Brothers, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W. [*Doucine, London.*]; and Kilmux, Leven.

1886. Duncan, Norman, Mechanical Engineer to the Municipality, Rangoon, British Burmah, India.

1870. Dunlop, James Wilkie, 39 Delancey Street, Regent's Park, London, N.W.

1881. Dunn, Henry Woodham, Knysna, Cape Colony; and Livonia, Goldsmith Gardens, Acton, London, W.

1890. Dunn, Hugh Shaw, Engineer, Caprington Collieries, Kilmarnock.

1885. Durham, Frederick William, 27 Leadenhall Street, London, E.C. [*Oilring, London.*]; and Glemham Lodge, New Barnet.

1886. Duvall, Charles Anthony, Lucigen Light Co., Page Street, Westminster, S.W.

1887. Dymond, George Cecil, Messrs. W. P. Thompson and Co., 6 Lord Street, Liverpool.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.

1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.

1888. Eaton-Shore, George, Borough Engineer, Temple Chambers, Crewe.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1844, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1886. Ede, Francis Joseph, Messrs. Ede Brothers, Silchar, Cachar, India.

1887. Edlin, Herbert William, Poste Restante, Cape Town, Cape Colony: (or The Limes, Ellerton Road, Surbiton, R. O., Kingston-on-Thames.)

1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.

1871. Edwards, Edgar James, 12 Dartmouth Street, Westminster, S.W.; and 42 Rye Hill Park, Peckham, London, S.E.

1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.

1888. Ellery, Henry George, 60 Norroy Road, Putney, London, S.W.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses. [*Elliot Company, London.*]

1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham. [*Elmeco, Birmingham.*]

1869. Elliott, Henry Worton, Selly Oak Works, near Birmingham. [*Elmeco, Birmingham.*]

1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1880. Ellis, Oswald William, 6 Grosvenor Place, Jesmond, Newcastle-on-Tyne. [*Robey, Newcastle-on-Tyne.*]

1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India; and 91 King Henry's Road, London, N.W.

1875. Elwell, Thomas, 223 Avenue de Paris, Plaine St. Denis, Seine, France.

1878. Elwin, Charles, London County Council, Spring Gardens, London, S.W.

1889. Emett, George Henry Hawkins, Hope Foundry, Dewsbury. [*Emett, Dewsbury.*]

1890. English, Lt.-Colonel Thomas, Palmer's Ordnance Works, Jarrow.

1885. Errington, William, 28 and 29 Insurance Buildings, Auckland, New Zealand. [*Refunditur, Auckland.*]

1890. Esson, John, Messrs. Blaikie Brothers, Footdee Iron Works, Aberdeen.

1889. Etches, Harry, Messrs. Etches Brothers, Eastbourne Engineering Works, Eastbourne.

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1887. Evans, Arthur George, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1884. Evans, David, Barrow Hæmatite Steel Works, Barrow-in-Furness.

1888. Evans, Joseph, Culwell Foundry, Wolverhampton.

1885. Evans, Richard Kendall, Engineering Works, Sandiacre, near Nottingham; and Whiston Grange, Rotherham.

1887. Everard, John Breedon, 6 Millstone Lane, Leicester.

1887. Everitt, Nevill Henry, Patent Shaft Works, Wednesbury; and Knowle Hall, Warwickshire.

1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.

1881. Ewen, Thomas Buttwell, Smithfield Works, Sherlock Street, Birmingham.

1890. Exton, George Gaskell, Messrs. Chubb and Son, 128 Queen Victoria Street, London, E.C.

1868. Fairbairn, Sir Andrew, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and Askham Richard, York.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and 69 Cornhill, London, E.C.

1882. Fawcett, Thomas Constantine, White House Engineering Works, Leeds. [*Fawcett, Leeds.*]

1884. Fearfield, John Piggin, Lace Machine Works, Stapleford, near Nottingham; and The Ferns, Stapleford, near Nottingham. [*Fearfield, Nottingham.*]

1888. Featherstone, William Bromley, Engineer and Manager, Dundalk Gas Works, Dundalk.

1882. Feeny, Victor Isidore, 7 Queen Victoria Street, London, E.C. [*Victor Feeny, London.*]

1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.

1877. Fenton, James, 8 Great George Street, Westminster, S.W.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E. [*Clennell, London.*]

1870. Ferguson, Henry Tanner, Wolleigh, Bovey Tracey, near Newton Abbot.

1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)

1854. Fernie, John, P. O. Box, Hutchinson, Kansas, United States.

1866. Fiddes, Walter, Clapton Villa, Belgrave Road, Tyndall's Park, Bristol.

1867. Field, Edward, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1888. Field, Howard, Messrs. John Bell and Son, 118A Southwark Street, London, S.E.; and Hillcote, Buckhurst Hill, S.O., Essex.

1884. Fielden, Joseph Petrie, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1887. Firth, William, Water Lane, Leeds.

1888. Fischer, Gustave Joseph, Tramway Construction Branch, Public Works Department, Beresford Chambers, Castlereagh Street, Sydney, New South Wales.

1889. Fisher, Henry Bedwell, Locomotive Works, London Brighton and South Coast Railway, Brighton.

1884. Fisher, Henry Oakden, Engineer, Taff Vale Railway, Cardiff.

1888. FitzGerald, Maurice Frederick, Professor of Engineering, Queen's College, Belfast.

1877. Flannery, James Forteseue, 9 Fenchurch Street, London, E.C. [2283.]

1883. Fletcher, George, Masson and Atlas Works, Litchurch, Derby.

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester. [*Steam Users', Manchester.*]

1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.

1887. Foley, Nelson, Engineering Manager, Società Industriale Napoletana Hawthorn-Guppy, Naples, Italy.

1886. Folger, William Mayhew, Commander, United States Navy, Bureau of Ordnance, Naval Department, Washington, D.C., United States.

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Bombay.

1882. Forbes, William George Loudon Stuart, Superintendent of General Workshops, H. M. Mint, Calcutta.

1888. Forster, Alfred Llewellyn, Assistant Engineer, Newcastle and Gateshead Water Works, Newcastle-on-Tyne.

1888. Forster, Edward John, Messrs. Chance Brothers and Co., Glass Works, Spon Lane, near Birmingham.

1882. Forsyth, Robert Alexander, Courtway, Gold Tops, Newport, Monmouthshire.

1889. Foster, Ernest Howard, Messrs. Henry R. Worthington, 86 Liberty Street, New York, United States.

1886. Foster, Frederick, Messrs. Barnett and Foster, Niagara Works, Eagle Wharf Road, New North Road, London, N. [*Drinks, London.* 306.]

1889. Foster, Herbert Anderton (*Life Member*), Messrs. John Foster and Son, Black Dike Spinning Mills, Queensbury, near Bradford.

1888. Foster, James, Samarang, Java; and Baltic Chambers, Sunderland. [*Java, Sunderland.*]

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Superintendent Marine Engineer, 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.

1885. Fourny, Hector Foster, Earle's Shipbuilding and Engineering Works, Hull.

1866. Fowler, George, Basford Hall, near Nottingham.

1847. Fowler, Sir John, Bart., K.C.M.G., 2 Queen Square Place, Westminster, S.W.

1885. Fowler, William Henry, Chadderton Iron Works, Irk Vale, Chadderton, near Oldham; and Poplar Villa, New Moston, Failsworth, near Manchester.

1866. Fox, Sir Douglas, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1882. Fox, William, Leeds Forge, Leeds.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.* 8007.]

1888. Francken, William Augustus, Public Works Department, India; care of Messrs. Grindlay Groom and Co., Bombay, India.

1885. Franki, James Peter, Morts Dock and Engineering Co., Morts Bay, Sydney, New South Wales: (or care of Messrs. Goldsbrough Mort and Co., 149 Leadenhall Street, London, E.C.)

1877. Fraser, John Hazell, 110 Cannon Street, London, E.C.

1888. Frenzel, Arthur Benjamin, 49 Warren Street, New York, United States.

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Barnsley Road, Sheffield.

1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.

1884. Furness, Edward, Messrs. Pontifex and Wood, Shoe Lane, London, E.C.; and Knollcroft, Knoll Road, Bexley, S.O., Kent.

1890. Gadd, William, Assistant Locomotive Carriage and Wagon Superintendent, Waterford and Limerick Railway, Limerick.

1887. Gaertner, Ernst, I. Fichtegasse 5, Vienna, Austria.

1866. Galloway, Charles John, Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]

1862. Galton, Sir Douglas, K.C.B., D.C.L., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1884. Ganga Ram, Lala, Executive Engineer, Public Works Department, Amritsar, Punjaub, India.

1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk. [*Garrett, Leiston.*]

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough. [*Pyrometer, Middlesbrough.*]

1888. Gaze, Edward Henry James, 4 Victoria Drive, Mount Florida, Glasgow.

1888. Geddes, Christopher, Leeds Forge, Leeds.

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin. [*Guinness, Dublin.*]

1887. Gibb, Andrew, Managing Engineer, Messrs. Rait and Gardiner, Millwall Docks, London, E.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham. [*Gibbins, Birmingham.*]

1883. Gilchrist, Percy Carlyle (*Life Member*), Palace Chambers, 9 Bridge Street, Westminster, S.W. [*Gilchrist, London*]; and Frognal Bank, Finchley New Road, Hampstead, London, N.W.

1856. Gilkes, Edgar, Westholme, Grange-over-Sands, viâ Carnforth, Lancashire.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1889. Gill, Frederick Henry, Messrs. Kerr Stuart and Co., 20 Bucklersbury, London, E.C.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]

1884. Girdlestone, John Ward, Engineer, Bristol Docks, Bristol.

1881. Girdwood, William Wallace, Indestructible Packing Works, 9 Lea Place, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1887. Gledhill, Manassah, Sir Joseph Whitworth and Co., Openshaw, Manchester.

1880. Godfrey, William Bernard, 23 St. Swithin's Lane, London, E.C.

1888. Goff, John, Messrs. Salt and Co., The Brewery, Burton-on-Trent.

1882. Goldsmith, Alfred Joseph, Messrs. John Walker and Co., Union Foundry and Shipbuilding Works, Maryborough, Queensland: (or care of Messrs. James McEwan and Co., 27 Lombard Street, London, E.C.)

1879. Goldsworthy, Robert Bruce, Messrs. Thomas Goldsworthy and Sons, Britannia Emery Mills, Hulme, Manchester. [*Goldsworthy, Manchester.*]

1867. Gooch, William Frederick, Vulcan Foundry, Newton-le-Willows, Lancashire.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.

1875. Goodfellow, George Ben, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]

1884. Goodger, Walter William, Messrs. George Fletcher and Co., Masson and Atlas Works, Litchurch, Derby.

1890. Goodman, John, Professor of Engineering, Yorkshire College, Leeds.

1885. Goodwin, Arnold, Jun., 56 Sumner Street, Southwark, London, S.E.

1889. Goold, William Tom, 39 Queen Victoria Street, London, E.C.; and 18 The Hawthorns, Finchley, London, N.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of James Bird, 118 Cannon Street, London, E.C.)

1887. Gordon, Alexander, Niles Tool Works, and Messrs. Gordon and Maxwell, Hamilton, Ohio, United States.

1875. Gordon, Robert, 112 Harrow Road, London, W.

1888. Gore, Arthur Saunders, 14 Cowley Street, Westminster, S.W.

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]

1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.

1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester. [*Indicator, Manchester.*]

1887. Gourlay, Charles Gershom, Messrs. Gourlay Brothers and Co., Dundee Foundry, Dundee.

1878. Grafton, Alexander, Vulcan Works, Bedford. [*Grafton, Bedford.*]

1865. Gray, John Macfarlane, Chief Examiner of Engineers, Marine Department, Board of Trade, St. Katharine Dock House, Tower Hill, London, E.; and 1 Claremont Road, Forest Gate, London, E. [*Yarg, London.*]

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1879. Gray, Thomas Lowe, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.; and Rokesley House, St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 8 Victoria Chambers, 15 Victoria Street, Westminster, S.W.

1861. Green, Sir Edward, Bart., M.P., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1888. Green, Henry Joseph Kersting, Engineer, Bishnauth Tea Co., Charalli Post Office, Assam, Bengal.

1871. Greener, John Henry, 15 Walbrook, London, E.C.

1890. Greening, William Alfred, 88 Bishopsgate Street Within, London, E.C.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry, Birmingham Small Arms and Metal Co., Adderley Park Works, Birmingham.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds. [*Greig, Fowler, Leeds.* 155.]

1879. Grenville, Robert Neville, Butleigh Court, Glastonbury.

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Ordsal Lane, Salford, Manchester. [*Brake, Manchester.*]

1883. Grew, Frederick, care of F. W. Grew, Victoria Iron Works, Sowerby Bridge.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1884. Griffiths, James E., Messrs. Griffiths and Wills, Merchants' Exchange, Cardiff. [*Griffwill, Cardiff.*]

1873. Griffiths, John Alfred, O'Keefe Estate, South Brisbane, Queensland.

1889. Grimshaw, James Walter, Resident Engineer, Harbours and Rivers Department, Sydney, New South Wales; and Australian Club, Sydney, New South Wales.

1879. Grose, Arthur, Messrs. Grose Norman and Co., Reliance Works, Northampton.

1886. Grove, David, 24 Friedrich Strasse, Berlin.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham. [*Cowen, Nottingham.* 87.]

1883. Guinotte, Lucien, Mariemont and Bascoup Collieries, Mariemont, Belgium.

1884. Gulland, James Ker, Diamond Drill Co., 8 Victoria Street, Westminster, S.W. [*Gulland, London.*]

1886. Guy, Charles Williams, Laurel Bank, Penge, London, S.E.

1870. Gwynne, James Eglinton Anderson (*Life Member*), Essex Street Works, Strand, London, W.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.; and 89 Cannon Street, London, E.C.

1888. Hadfield, Robert Abbott, Hecla Foundry Steel Works, Sheffield. [*Hadfield, Sheffield.*]

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., 111 Federal Street, Boston; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1879. Hall, John Francis, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1881. Hall, John Percy, Managing Director, Messrs. John Penn and Sons, Greenwich, London, S.E.

1882. Hall, John William, Ivy House, Bilston.

1890. Hall, Oscar Standring, Messrs. Robert Hall and Sons, Hope Foundry, Bury.

1874. Hall, Thomas Bernard, 119 Colmore Row, Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham.

1886. Hall, William Jeremiah, Harbour Engineer, Limerick, Ireland.

1871. Hall, William Silver, Messrs. Takata and Co., Ginza San Chome 18, Banchi, Tokio, Japan; and 88 Bishopsgate Street Within, London, E.C.

1889. Hall-Brown, Ebenezer, Messrs. Thomas Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1880. Hallett, John Harry, 120 Powell's Place, Bute Docks, Cardiff. [*Consulting, Cardiff.*]

1871. Halpin, Druitt, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W. [*Halpin, London.* 3075, care of Victoria Chambers Co.]

1888. Hamilton, Alfred George, 14 Griffin Street, York Road, London, S.E.

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Jundiahy, São Paulo, Brazil; (or care of Messrs. Lewis and Hyland, New Rents, Ashford, Kent.)

1886. Hanbury, John James, Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Neasden, London, N.W.

1870. Hannah, Joseph Edward, Water Works, Winnipeg, Manitoba, Canada.

1888. Harada, Torazo, Superintending Engineer, Osaka Shipping Co., Osaka, Japan.

1888. Harding, Thomas Walter, Tower Works, Leeds.

1874. Harding, William Bishop, Zerge-utcza 13, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C. [*Hardingham, London.*]

1883. Hardy, John George, 13 Riemergasse, Stadt, Vienna.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1887. Hargraves, Richard, Messrs. B. Donkin and Co., Southwark Park Road, Bermondsey, London, S.E.

1887. Hargreaves, John Henry, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1884. Harker, Harold Hayes, Locomotive Superintendent, Minas and Rio Railway, Cruzeiro, Rio de Janeiro, Brazil: (or care of Jesse T. Curtis, Hill Street, Poole.)

1888. Harker, William, Messrs. Richard Schram and Co., 17A Great George Street, Westminster, S.W.

1888. Harland, Sir Edward James, Bart., M.P., Messrs. Harland and Wolff, Belfast; Glenarm Castle, County Antrim; and Baroda House, Kensington Palace Gardens, London, W.

1873. Harman, Harry Jones, 36 Gaisford Street, Kentish Town, London, N.W.

1879. Harris, Henry Graham, 5 Great George Street, Westminster, S.W.

1885. Harris, John Henry, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C. [*Tuneharp, London.*]

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.; and Oak Hill, Surbiton, R.O., near Kingston-on-Thames.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln. [*Malleable, Lincoln.*]

1888. Harrison, George, 21 Hillsboro Road, East Dulwich, London, S.E.

1885. Harrison, Joseph, Normal School of Science, South Kensington, London, S.W.

1887. Harrison, Thomas Henry, Messrs. Davey Paxman and Co., 139 Queen Victoria Street, London, E.C.; and 22 Granville Villas, Earlsfield Road, Wandsworth, London, S.W.

1890. Harrison, William Robert, Manager, Hull Cart and Wagon Co., Newington Iron Works, Hull.

1883. Hart, Frederick, 36 Prospect Street, Poughkeepsie, New York, United States: (or care of A. Pye-Smith, Messrs. Samuel Osborn and Co., 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.)

1882. Hart, Norman, London Chatham and Dover Railway, Locomotive (Marine) Department, Dover.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1886. Harvey, John Boyd, The Liverpool Nitrate Co., Oficina Ramirez, Iquique, Chile: (or care of Robert Harvey, 12 Kensington Gore, London, S.W.)

1883. Harvey, Robert, 12 Kensington Gore, London, S.W.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1882. Haskins, John Ferguson, 114A Queen Victoria Street, London, E.C. [*Haskins, London.* 1539.]; and Fallulah, York Road, West Norwood, London, S.E.

1881. Haslam, Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]

1858. Haswell, John A., Ravensworth Crescent, Low Fell, near Gateshead.

1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.

1888. Hattori, Shiun-ichi, Owari Cotton Mill, Atsuta, Owari, Japan.

1857. Haughton, S. Wilfred (*Life Member*), Greenbank, Carlow, Ireland.

1878. Haughton, Thomas, 110 Cannon Street, London, E.C. [*Haughnot, London.*]

1885. Haughton, Thomas James, 27 Piccadilly, London, W.

1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.
1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.
1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.
1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.
1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]
1879. Hayes, John, Messrs. Francis Morton and Co., Hamilton Iron Works, Garston, Liverpool.
1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.
1888. Head, Harold Ellershaw, Messrs. Conway Brothers, Pontrhydyrun Works, near Newport, Moumouthshire.
1869. Head, Jeremiah, Queen's Square, Middlesbrough [*Head, Middlesbrough*]; and 26 Lombard Street, London, E.C.
1873. Headly, Lawrance, Exchange Iron Foundry and Implement Works, Corn Exchange Street, Cambridge; and Yorke House, Newmarket Road, Cambridge. [*Vanes, Cambridge.*]
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1872. Heap, William, 9 Rumford Place, Liverpool. [*Metal, Liverpool.* 809.]
1889. Heath, George Wilson, Messrs. Heath and Co., Observatory Works, Crayford, Kent.
1888. Heatly, Harry, 30 Strand, Calcutta, India.
1875. Heenan, Richard Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester; and Whitehall, Brooklands, near Manchester. [*Spherical, Newton Heath.*]
1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.
1883. Henderson, John Baillie, Engineer to the Queensland Government, Water Supply Department, Brisbane, Queensland.
1883. Henderson, William, Engineer, South East Mysore Gold Mine, near Colar Road, Mysore, India.
1878. Henesey, Richard, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay; and 3 Beckett Terrace, Uxbridge.
1888. Henning, Gustavus Charles, 726 Temple Court, 5 Beekman Street, New York, United States.
1879. Henriques, Cecil Quixam, 113 Cannon Street, London, E.C.
1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool. [*Hepburn, Liverpool.*]
1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.
1884. Hernu, Arthur Henry, 69 Victoria Street, Westminster, S.W.
1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh Dartford.*]
1872. Hewlett, Alfred, Haseley Manor, Warwick.
1887. Hibbert, George, Hibbert's Works, Bank Road, Gateshead-on-Tyne.
1871. Hick, John, Mytton Hall, Whalley, near Blackburn.
1885. Hicken, Thomas, care of Messrs. Alexander Shanks, Hijos and Co., 416 Calle Alsina, Buenos Aires, Argentine Republic: (or care of John Hicken, Bourton, near Rugby.)
1864. Hide, Thomas C., 4 Cullum Street, Fenchurch Street, London, E.C.
1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.
1889. Hill, Arthur Ripley, Messrs. Hill Brothers, Nevins Foundry, Hunslet, Leeds.
1885. Hill, Robert Anderson, Royal Mint, Little Tower Hill, London, E.
1890. Hiller, Edward George, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.
1882. Hiller, Henry, Chief Engineer, National Boiler Insurance Company, 22 St. Ann's Square, Manchester.
1873. Hilton, Franklin, General Works Manager, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough; and South Bank, R.S.O., Yorkshire.
1887. Hindson, William, Messrs. J. Abbot and Co., Park Works, Gateshead.
1870. Hodges, Petronius, 142 Burngreave Road, Sheffield.
1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.
1889. Hodgson, George Herbert, Thornton Road, Bradford.
1882. Hodson, Richard, Thames Iron Works and Shipbuilding Co., Blackwall, London, E.
1889. Hoggins, Alfred Farquharson, Messrs. Fowler Lancaster and Co., Albert Works, Graham Street, Birmingham.
1866. Holcroft, Thomas, Bilston Foundry, Bilston.
1886. Holden, James, Locomotive Superintendent, Great Eastern Railway, Stratford Works, London, E.
1884. Holland, Calvert Bernard, General Manager, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.
1886. Hollis, Charles William, Messrs. Ketton and Hollis, Meadow Tool Works, Mayfield Grove, Nottingham.
1885. Hollis, Henry William, Thornville House, Darlington.
1883. Holroyd, John, Tomlinson Street, Hulme, Manchester. [*Knit, Manchester.*]
1885. Holroyd, John Herbert, West's Patent Press Company, Etawah, N.W. Provinces, India.
1863. Holt, Francis, Locomotive Department, Midland Railway, Derby.
1873. Holt, Henry Percy, The Cedars, Didsbury, Manchester.

1890. Holt, Robert, Lecturer in Engineering, Walker Engineering Laboratories, Brownlow Hill, Liverpool.

1890. Holt, William Procter, Orconera Iron Ore Co., Apartado 42, Bilbao, Spain.

1888. Homan, Harold, Messrs. Homan and Rodgers, Dawson Street, Manchester.

1867. Homer, Charles James, Mining Engineer, Ivy House, Stoke-upon-Trent.

1890. Hooker, Benjamin, Pear Tree Court, Farringdon Road, London, E.C.

1883. Hooton, William, Continental Lace-Machine Works, Great Eastern Street, Nottingham.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1885. Hopkinson, Charles, Werneth Chambers, 29 Princess Street, Manchester.

1856. Hopkinson, John, Inglewood, St. Margaret's Road, Bowdon, near Altrincham.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham; and 3 Westminster Chambers, 5 Victoria Street, Westminster, S.W. [3092.]

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1890. Hopper, Allan, Messrs. William Hopper and Co., Moscow, Russia.

1890. Hopper, James Russell, Messrs. William Hopper and Co., Moscow, Russia.

1889. Hopwood, John, Locomotive Superintendent, Argentine Great Western Railway, Mendoza, Argentine Republic.

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham. [*Hornsbys, Grantham.*]

1889. Horsfield, Cooper, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1858. Horsley, William, Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, 4 Cedars Road, Clapham Common, London, S.W.

1886. Hosgood, John Howell, Locomotive and Hydraulic Superintendent, Barry Dock and Railways, Barry, near Cardiff.

1875. Hosgood, Thomas Hopkin, Richardson Street, Swansea.

1889. Hosken, Richard, Severn Tunnel Works, Sudbrook, near Chepstow.

1873. Hoskin, Richard, 8 Norfolk Street, Sheffield.

1888. Hosking, Thomas, Messrs. T. and J. Hosking, Dockhead Iron Works, 53 Parker's Row, Bermondsey, London, S.E.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1889. Houghton, Thomas Harry, Water Works, Crown Street, Sydney, New South Wales: (or care of Messrs. James Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.)

1887. Houghton-Brown, Ernest, Messrs. Houghton-Brown Brothers, Kingsbury Iron Works, Ballspond, London, N.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1879. Howard, James Harold, Britannia Iron Works, Bedford; and Kempston Grange, Bedford.

1882. Howard, John William, 78 Queen Victoria Street, London, E.C.

1885. Howarth, William, Manager, Oldham Boiler Works, Oldham. [*Boilers Oldham.*]

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1882. Howl, Edmund, Messrs. Lee Howl and Co, Tipton. [*Howl, Tipton.*]

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W. [*Brickpress, London.*]

1884. Hoyle, Frank Edward, care of E. Irving, 14 Bryanstone Road, St. Michaels, Liverpool.

1887. Hoyle, James Rossiter, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1882. Hudson, John George, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton; and Glenholme, Bromley Cross, Bolton.

1884. Hudson, Robert, Gildersome Foundry, near Leeds [*Gildersome, Leeds.* 14.]; and Weetwood Mount, Headingley, near Leeds. [454.]

1881. Hughes, Edward William Mackenzie, Locomotive and Carriage Superintendent, North-Western State Railway, Sukkur, Sindh Section, India; Eriestane, Helensburgh; and care of Messrs. H. S. King and Co., 45 Pall Mall, London, S.W.

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1889. Hughes, John, Messrs. Hughes and Lancaster, City Road, Chester.

1871. Hughes, Joseph, Kingston, Wareham.

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Tool Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1864. Hulse, William Wilson, Ordsal Tool Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1890. Humphries, Edward Thomas, Messrs. Edward Humphries and Co., Atlas Iron Works, Pershore.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1882. Hunt, Reuben, Aire and Calder Chemical Works, Castleford, near Normanton.

1885. Hunt, Richard, Messrs. Thomas Hunt and Sons, Albion Iron Works, 132 Bridge Road West, Battersea, London, S.W.

1856. Hunt, Thomas, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1874. Hunt, William, Alkali Works, Lea Brook, Wednesbury; Hampton House, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1889. Hunter, Charles Lafayette, Engineer, Bute Docks, Cardiff.

1886. Hunter, John, Messrs. Campbells and Hunter, Dolphin Foundry, Saynor Road, Hunslet, Leeds.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E. [*Venator, London.*]

1888. Huxley, George, 20 Mount Street, Manchester.

1885. Hyland, John Frank, Railway Contractor, São Carlos do Pinhal, Estado de São Paulo, Brazil: (or care of Messrs. Lewis and Hyland, New Rents, Ashford, Kent.)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, Assistant Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.

1888. Ingleby, Joseph, 20 Mount Street, Manchester.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead.

1883. Instone, Thomas, 22 Leadenhall Buildings, Leadenhall Street, London, E.C.

1889. Irvine, William Charles, Messrs. Irvine and Co., Harbour Dockyard, West Hartlepool.

1887. Ivatt, Henry Alfred, Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1887. Ivatts, Lionel Edward, 50 Avenue de la Grande Armée, Paris.

1884. Jacks, Thomas William Moseley, Patent Shaft Works, Wednesbury; and Woodgreen, Wednesbury.

1859. Jackson, Matthew Murray, 47 Norton Road, West Brighton, Brighton; and care of Messrs. Howard and Pitcairn, 155 Fenchurch Street, London, E.C.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire. [*Jacksons, Manchester.*]

1873. Jackson, Samuel, C.I.E., Locomotive and Carriage Superintendent, Great Indian Peninsula Railway, Bombay.

1886. Jackson, Thomas, Yorkshire College, Leeds.

1889. Jackson, William, Thorn Grove, Mannofield, Aberdeen.

1872. Jackson, William Francis, Sterndale House, Litton, near Stockport.

1873. Jacob, Edward Westley, 3 Woodside Terrace, Grange Road, Darlington.

1876. Jacobs, Charles Mattathias, 88 Bishopsgate Street Within, London, E.C. [*Vexillum, London.*]

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1889. James, Charles William, New York Oxygen Co., 80 Broadway, New York, United States.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1877. James, John William Henry, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1889. James, Reginald William, 1 Queen Victoria Street, London, E.C.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne. [*Jameson, Newcastle-on-Tyne.* 226.]

1888. Jaques, Lieut. William Henry, Secretary to Ordnance Committee, United States; and Bethlehem Iron Works, Bethlehem, Pa., United States.

1888. Jeejeebhoy, Piroshaw Bomanjee, 17 Church Street, Bombay, India.

1880. Jefferies, John Robert, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1877. Jeffreys, Edward Homer, Hawkhills, Chapel Allerton, Leeds.

1884. Jenkins, Alfred, Wharncliffe, Victoria Road, Penarth.

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1878. Jensen, Peter, 77 Chancery Lane, London, W.C. [*Venture, London.*]

1889. Jessop, George, London and Leicester Steam-Crane and Engine Works, Leicester.

1886. Jewell, Henry William, Messrs. Jewell and Son, City Foundry, Winchester.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 9 Upper Northgate Street, Chester.

1882. Johnson, Charles Malcolm, Inspector of Machinery, Superintending Engineer, H.M. Dockyard, Bermuda; and 11 Napier Street, Stoke, Devonport.

1885. Johnson, John Clarke, Messrs. James Russell and Sons, Crown Tube Works, Wednesbury.

1890. Johnson, John William, Messrs. John M. Sumner and Co., Moscow, Russia; and care of Baron Knoop, Grande Loubianka, Moscow, Russia.

1888. Johnson, Lawrence Potter, Assistant Locomotive Superintendent, Burma State Railway, Insein, British Burma.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale.

1887. Johnson, Samuel Henry, Engineering Works, Carpenter's Road, Stratford, London, E.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1888. Johnson, William, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne. [*Engines, Newcastle-on-Tyne.*]

1882. Jolin, Philip, 35 Narrow Wine Street, Bristol; and 2 Elmdale Road, Redland, Bristol.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Messrs. Greenwood and Batley, Albion Works, Leeds; and De Grey Lodge, De Grey Road, Woodhouse Lane, Leeds.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, District Locomotive Superintendent, North Western Railway, Multan, Punjaub, India: (or care of Mrs. Edward Jones, 9 Sydenham Villas, Cheltenham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive Department, Midland Railway, Manchester.

1890. Jones, Morlais Glasfryn, 6 Delahay Street, Westminster, S.W.

1882. Jones, Samuel Gilbert, Hatherley Court, Gloucester.

1887. Jones, Thomas, Central Board School, Deansgate, Manchester.

1872. Jones, William Richard Sumption, Rajputana State Railway, Ajmeer, India: 3 Northumberland Avenue, Putney, London, S.W.: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.

1880. Joy, David, 8 Victoria Chambers, 15 Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1878. Jüngermann, Carl, Maschinenbau Actien Gesellschaft Vulcan, Bredow bei Stettin, Germany.

1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C. [*Syng, London.* 2504.]

1889. Kanthack, Ralph, Sub-Manager, Carl Zeiss' Optical Works, Jena, Germany.

1888. Kapteyn, Albert, Westinghouse Brake Co., Canal Road, York Road, King's Cross, London, N.

1882. Keeling, Herbert Howard, Merlewood, Eltham.

1869. Keen, Arthur, London Works, near Birmingham. [*Globe, Birmingham.*]

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Westbromwich.

1867. Kellett, John, Clayton Street, Wigan.

1873. Kelson, Frederick Colthurst, Angra Bank, Waterloo Park, Waterloo, near Liverpool.

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Gateshead.

1879. Kennedy, Professor Alexander Blackie William, F.R.S., 19 Little Queen Street, Westminster, S.W. [*Kinematic, London.*]

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1868. Kennedy, Thomas Stuart, Parkhill, Wetherby.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Whetstone, Somerset Road, Edgbaston, Birmingham.

1888. Kershaw, Frederic, Evans y Livock, 228 Calle Piedad, Buenos Aires, Argentine Republic.

1866. Kershaw, John, Marazion, St. Leonard's-on-Sea.

1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.

1887. Key, Alexander, 36A City Buildings, Old Hall Street, Liverpool.

1890. Key, George Andrew, care of J. Dunn, Tattersall's Chambers, Hunter Street, Sydney, New South Wales: (or care of Alexander Key, 36A City Buildings, Old Hall Street, Liverpool.)

1885. Keydell, Amandus Edmund, Lloyd's Register of Shipping, Dundee.

1885. Keyworth, Thomas Egerton, Ferro Carril Buenos Aires y Rosario, Campana, Buenos Aires, Argentine Republic: (or care of J. R. H. Keyworth, 25 Park Road South, Birkenhead.)

1885. Kidd, Hector, Colonial Sugar Refining Co., Sydney, New South Wales.

1888. Kikuchi, Kyozo, Superintendent Engineer, Hirano Spinning Mill, Osaka, Japan.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1889. Kirby, Frank Eugene, Constructing Engineer, Detroit Dry Dock Co., Detroit, Michigan, United States.

1872. Kirk, Alexander Carnegie, LL.D., Messrs. Robert Napier and Sons, Lancefield House, Glasgow; and Govan Park, Govan, Glasgow.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington. [*Kirks, Workington.*]

1884. Kirkaldy, John, 40 West India Dock Road, London, E. [*Compactum, London.*]

1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Commissioner of Customs, Kowloon, Hong Kong, China: (or Melita Cottage, Denny.)

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W. [3005.]

1859. Kitson, Sir James, Bart., Monk Bridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds. [*Airedale, Leeds.*]

1874. Klein, Thorvald, Suffolk House, 5 Laurence Pountney Hill, London, E.C.

1889. Knap, Conrad, 11 Queen Victoria Street, London, E.C.

1886. Knight, Charles Albert, Babcock and Wilcox Boiler Co., 107 Hope Street, Glasgow.

1890. Knight, James Percy, District Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.

1889. Knox, James, Civil and Mechanical Engineer, Auckland, New Zealand: (or care of E. D. Knox, 53 Belsize Park Gardens, South Hampstead, London, N.W.)

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1883. Lake, William Robert, 45 Southampton Buildings, London, W.C. [*Scopo, London.*]

1878. Lambourn, Thomas William, Naughton Hall, near Bildeston, S.O., Suffolk.

1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of T. C. Langdon, Tamar Terrace, Launceston.)

1881. Lange, Frederick Montague Townshend, Messrs. Lange's Wool-Combing Works, Saint Acheul-les-Amiens, Somme, France.

1877. Lange, Hermann Ludwig, Manager, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Langley, Alfred Andrew, 33 Chester Terrace, Regent's Park, London, N.W.

1879. Lapage, Richard Herbert, 17 Austin Friars, London, E.C. [*Lapage, London.*]

1890. Last, Arthur John, Oulton, Abbeville Road, Balham, London, S.W.

1888. Latham, Baldwin, 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.

1890. Laurie, Leonard George, Mill Parade, Newport, Monmouthshire.

1881. Lavalley, Alexander, 48 Rue de Provence, Paris.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 5 Winchester Terrace, Newcastle-on-Tyne. [*Engineer, Newcastle-on-Tyne.*]

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Layborn Patterson and Co., Dutton Street, Liverpool.

1883. Laycock, William S., Messrs. Samuel Laycock and Sons, Horse-hair Cloth Works, Sheffield; and Ranmoor, Sheffield.

1860. Lea, Henry, Messrs. Henry Lea and Thornbery, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1889. Leaf, Henry Meredith, Messrs. Crompton and Co., Mansion House Buildings, Queen Victoria Street, London, E.C.

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1865. Ledger, Joseph, 7 North Terrace, Darlington.

1890. Ledingham, John Machray, Royal Laboratory, Royal Arsenal, Woolwich.

1886. Lee, Charles Eyre, 18 Newhall Street, Birmingham.

1887. Lee, Cuthbert Ridley, Messrs. J. Coates and Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1862. Lee, J. C. Frank, 9 Park Crescent, Portland Place, London, W.

1890. Lee, Samuel Edward, Messrs. Harrison Lee and Sons, City Foundry, Limerick.

1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton; and 110 Cannon Street, London, E.C.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1889. Legros, Lucien Alphonse, 57 Brook Green, Hammersmith, London, W.

1883. Lennox, John, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1858. Leslie, Andrew, Coxlodge Hall, Newcastle-on-Tyne.

1888. Leslie, Sir Bradford, K.C.I.E., Tarrangower, Willesden Lane, Brondesbury, London, N.W.

1883. Leslie, Joseph, Marine Engineer, Messrs. Apcar and Co., Raddah Bazar, Calcutta.

1888. Letchford, Joseph, Manager, Messrs. David Munro and Co., Stuart Street, Melbourne, Victoria; care of Richard Speight, Glenroy Park, Hampton Street, Middle Brighton, Melbourne, Victoria: (or care of James Letchford, 370 Wandsworth Road, London, S.W.)

1878. Lewis, Gilbert. 37 Monton Street, Moss Side, Manchester.

1884. Lewis, Henry Watkin, Llwyn-yr-eos, Abercanaid, near Merthyr Tydfil.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1887. Lewis, Rowland Watkin, Messrs. Edwin Lewis and Sons, Britannia Boiler Tube Works, Wolverhampton.

1884. Lewis, Sir William Thomas, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Separator, London.*]; and 7 Eastcombe Villas, Charlton Road, Blackheath, London, S.E.

1887. Lindsay, Joseph, Messrs. Urquhart Lindsay and Co., Blackness Foundry, Dundee.

1890. Lineham, Wilfrid James, Professor of Engineering and Mechanical Science, Goldsmiths' Company's Technical Institute, New Cross, London, S.E.; and Jesmond, Leyland Road, Lee, London, S.E.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.; and 3 St. John's Park, Blackheath, London, S.E.

1885. Lister, Frank, Messrs. Lister and Co., Beechcliffe, Keighley; and Oaklands, Keighley.

1890. Lister, Robert Ramsbottom, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1890. Livens, Frederick Howard, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1867. Livesey, James, 29, 30 and 31 Broad Street Avenue, London, E.C.

1886. Livsey, John Edward, Demonstrator in Mechanics and Mathematics, Normal School of Science, South Kensington, London, S.W.

1867. Lloyd, Charles, New Athenæum Club, 26 Suffolk Street, Pall Mall, London, S.W.

1871. Lloyd, Francis Henry, James Bridge Steel Works, near Wednesbury [*Steel, Wednesbury*]; and Wood Green, Wednesbury.

1854. Lloyd, George Braithwaite (*Life Member*), Edgbaston Grove, Birmingham.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.

1890. Locke, Arthur Guy Neville, Universal Barrel Works, Two Waters Mill, Boxmoor, near Hemel Hempstead.

1879. Lockhart, William Stronach, 67 Granville Park, Blackheath, London, S.E.

1881. Lockyer, Norman Joseph, care of Sir A. M. Rendel, 8 Great George Street, Westminster, S.W.

1884. Logan, Andrew Linton, Vulcan Foundry, Newton-le-Willows, Lancashire.

1890. Logan, John Walker, Messrs. Richard Hornsby and Sons, P. O. Box 216, Johannesburg, Transvaal, South Africa.

1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.

1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.

1884. Longbottom, Luke, Locomotive Carriage and Wagon Superintendent, North Staffordshire Railway, Stoke-on-Trent.

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.

1880. Longworth, Daniel, Messrs. D. Longworth and Co., Alma Street Works, Sheffield; and 5 and 7 Fenchurch Street, London, E.C.

1887. Lorrain, James Grieve, Norfolk House, Norfolk Street, London, W.C. [*Lorrain, London.*]

1888. Low, David Allan, Lecturer on Engineering, The People's Palace Technical Schools, Mile End Road, London, E.

1861. Low, George, Bishop's Hill Cottage, Ipswich.

1885. Low, Robert, Eildon House, Macaulay Road, Clapham Common, London, S.W.

1884. Lowcock, Arthur, Coleham Foundry, Shrewsbury.

1884. Lowdon, John, General Manager, Barry Graving Dock and Engineering Co., Exchange Buildings, Cardiff. [*Bardock, Cardiff.*]

1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C. [*Bird, London.* 1530.]

1887. Loynd, John Shaw, Apartado 696, City of Mexico, Mexico.

1873. Lucas, Arthur, 27 Bruton Street, New Bond Street, London, W.

1889. Lucy, Arthur John, Messrs. Turner Morrison and Co., Sugar Works, Cossipore, Calcutta, India.

1886. Lucy, William Theodore, Locomotive Department, London Brighton and South Coast Railway, Brighton: (or Thornleigh, Woodstock Road, Oxford.)

1889. Lundon, Robert, Engineer's Department, Rosstown Junction Railway and Property Co., Bourke Street East, Melbourne, Victoria; and 66 Elizabeth Street, Melbourne, Victoria.

1877. Lupton, Arnold, Professor of Mining Engineering, Yorkshire College, Leeds; and 6 De Grey Road, Leeds. [*Arnold Lupton, Leeds.* 330.]

1887. Lupton, Kenneth, 6 Gordon Terrace, Cope Street, Coventry.

1878. Lynde, James Henry, 32 St. Ann's Street, Manchester.

1889. Macallan, George, Works Manager, Great Eastern Railway, Stratford Works, London, E.

1890. Macan, Richard Thompson, Dawlish House, Willesden, London, N.W.

1888. Macbeth, John Bruce King, 44 Tamarind Lane, Bombay, India: (or care of Norman Macbeth, Heaton, Bolton.)

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1890. MacBrair, William Maxwell, Sheaf Island Works, Sheffield.

1884. MacCarthy, Samuel, Messrs. Lloyd and Lloyd, 90 Cannon Street, London, E.C.; and 6 Endwell Road, Brockley, London, S.E.

1877. MacColl, Hector, Messrs. MacIlwaine and MacColl, Ulster Iron Works, Belfast.

1879. Macdonald, Augustus Van Zundt, Locomotive Engineer, Addington, Christchurch, New Zealand.

1889. Macdonald, James Alexander, Broad Oaks Iron Works, Chesterfield.

1890. Mackay, Joseph, Bangkok Dock Co., Bangkok, Siam: (or care of Messrs. John Birch and Co., 10 Queen Street Place, London, E.C.) [*Mackay, Bangkok.*]

1885. Mackenzie, John William, Messrs. Wheatley and Mackenzie, 40 Chancery Lane, London, W.C.; and Northfield, Oxford Road, Upper Teddington, S.O., Middlesex.

1875. Maclagan, Robert, care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.

1889. MacLay, Alexander, Professor of Mechanical Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1886. MacLean, Alexander Scott, Messrs. Alexander Scott and Sons, Sugar Refinery, Berry-yards, Greenock.

1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1888. Macleod, Arthur William, Messrs. John Fowler and Co., 5 Mangoe Lane, Calcutta, India.

1864. Macnab, Archibald Francis, Inspecting and Examining Engineer, Government Marine Office, Tokio, Japan.

1865. Macnee, Daniel, 2 Westminster Chambers, 3 Victoria Street, Westminster, S.W. [*Macnee, London.*]; and Rotherham.

1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1879. Maginnis, James Porter, 9 Carteret Street, Queen Anne's Gate, Westminster, S.W. [*James Maginnis, London*]; and 70 and 71 Tower Chambers, Finsbury Pavement, London, E.C. [*Offsett, London.*]

1873. Mair-Rumley, John George, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Screwcock, London.*]

1884. Mais, Henry Coathupe, 61 Queen Street, Melbourne, Victoria.

1888. Maitland, Eardley, Major-General, R.A., 111 New Bond Street, London, W.

1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1888. Mano, Bunji, Professor of Mechanical Engineering, Imperial University, Tokyo, Japan.

1875. Mansergh, James, 3 Westminster Chambers, 5 Victoria Street, Westminster, S.W.

1862. Mappin, Sir Frederick Thorpe, Bart., M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1878. Marié, Georges, Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, Bureaux du Matériel, Boulevart Mazas, Paris.

1888. Marks, George Croydon, 13 Temple Street, Birmingham. [*Pumps, Birmingham.*]

1884. Marquand, Augustus John, Pierhead Chambers, Cardiff. [*Electranode, Cardiff.*]

1887. Marriott, William, Engineer and Locomotive Superintendent, Eastern and Midlands Railway, Melton Constable, Norfolk.

1887. Marsden, Benjamin, Messrs. S. Marsden and Son, Screw-Bolt and Nut Works, London Road, Manchester.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Alfred (*Life Member*), Feckenham, Redditch.

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1890. Marshall, Frank Herbert, Ormesby Iron Works, Middlesbrough.

1885. Marshall, Henry Dickenson, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1885. Marshall, Jenner Guest, Westcott Barton Manor, Oxfordshire.

1877. Marshall, William Bayley, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1847. Marshall, William Prime, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1859. Marten, Edward Bindon, Pedmore, Stourbridge. [*Marten, Stourbridge.* 8504.]

1853. Marten, Henry John, The Birches, Codsall, near Wolverhampton; and 4 Storey's Gate, Westminster, S.W.

1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.

1878. Martin, Henry, Enderley, Lodge Road, Southampton.

1888. Martin, Henry James, Tresleigh House, Walters Road, Swansea.

1889. Martin, The Hon. James, Messrs. James Martin and Co., Phœnix Foundry, Gawler, South Australia: (or care of J. C. Lanyon, 27 Gresham House, Old Broad Street, London, E.C.)

1886. Martin, William Hamilton, Engineering Manager, The Scheldt Royal Shipbuilding and Engineering Works, Flushing, Holland.

1882. Martindale, Warine Ben Hay, 82 New Bond Street, London, W.; and Overfield, Bickley, R.S.O., Kent.

1882. Masefield, Robert, Manor Iron Works, Manor Street, Chelsea, London, S.W.

1884. Massey, George, Post Office Chambers, Pitt Street, Sydney, New South Wales.

1890. Massey, Stephen, Messrs. B. and S. Massey, Openshaw, Manchester.

1867. Mather, William, M.P., Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1883. Mather, William Penn, Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1882. Matheson, Henry Cripps, care of Messrs. Russell and Co., Hong Kong, China: (or care of Messrs. Matheson and Grant, 32 Walbrook, London, E.C.)

1875. Matthews, James, 22 Ashfield Terrace East, Newcastle-on-Tyne.

1886. Matthews, Robert, Parrs House, Heaton Mersey, near Manchester.

1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1853. Maudslay, Henry (*Life Member*), Westminster Palace Hotel, 4 Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.)

1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C. [3663.]

1884. Maxim, Hiram Stevens, Maxim Nordenfelt Guns and Ammunition Co., Victoria Mansions, 32 Victoria Street, Westminster, S.W.

1859. Maylor, William, Chesterleigh, Albemarle Road, Beckenham.

1874. McClean, Frank, Norfolk House, Norfolk Street, Strand, London, W.C.

1878. McDonald, John Alexander, Assistant Engineer for Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)

1865. McDonnell, Alexander, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.; and The Cedars, Norwood Green, Southall.

1881. McGregor, Josiah, Crown Buildings, 78 Queen Victoria Street, London, E.C. [*Sahib, London.*]

1889. McIntyre, John Henry A., Lecturer on Mechanical Engineering, Allan Glen's School, Glasgow.

1881. McKay, John, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. McLaren, Henry, Messrs. J. and H. McLaren, Midland Engine Works, Leeds.

1882. McLaren, Raynes Lauder, 32 Wemyss Road, Blackheath, London, S.E.

1888. McLarty, Farquhar Matheson, Penang Foundry, Penang: (or care of William Bow, Thistle Engine Works, Paisley.)

1879. McLean, William Leckie Ewing, Lancefield Forge Co., Glasgow.

1885. McNeil, John, Messrs. Aitken McNeil and Co., Helen Street, Govan, Glasgow. [*Colonial, Glasgow.*]

1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.

1881. Meik, Charles Scott, care of P. Walter Meik, 16 Victoria Street, Westminster, S.W.

1858. Meik, Thomas, 21 York Place, Edinburgh.

1887. Melhuish, Frederick, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1888. Melville, William Wilkie, 284 Ivydale Road, Nunhead, London, S.E.

1878. Menier, Henri, 56 Rue de Châteaudun, Paris.

1876. Menzies, William, Messrs. Menzies and Co., 50 Side, Newcastle-on-Tyne. [*William Menzies, Newcastle-on-Tyne. G.P.O.* 200. *Nor. Dis.* 1144.]

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre London, W.C. [*Merryweather, London.*]

1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.

1884. Middleton, Reginald Empson, 49 Parliament Street, Westminster, S.W.

1886. Midelton, Thomas, Aylesbury, Albemarle Street, North Kingston, Sydney, New South Wales.

1862. Miers, Francis C., Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham. [*Foundation, London.* 1920.]

1864. Miers, John William, 74 Addison Road, Kensington, London, W.

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1887. Miles, Frederick Blumenthal, Messrs. Bement Miles and Co., Callowhill and Twenty-first Streets, Philadelphia, United States.

1889. Miller, Adam, 205 Mansion House Chambers, 11 Queen Victoria Street, London, E.C.

1885. Miller, Harry William, care of Messrs. Chester and Gibb, Johannesburg, Transvaal, South Africa.

1886. Miller, John Smith, Messrs. Smith Brothers and Co., Hyson Green Works, Nottingham.

1887. Miller, Thomas Lodwick, 19 Percy Street, Liverpool.

1885. Millis, Charles Thomas, Technical College, Finsbury, London, E.C.

1887. Milne, William, Locomotive Superintendent, Natal Government Railways, Durban, Natal.

1856. Mitchell, Charles, Sir W. G. Armstrong Mitchell and Co., Low Walker, Newcastle-on-Tyne; and Jesmond Towers, Newcastle-on-Tyne.

1870. Moberly, Charles Henry, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1885. Moir, James, Superintendent Engineer, Bombay Steam Navigation Co., Frere Road, Bombay.

1879. Molesworth, Sir Guilford Lindsay, K.C.I.E., The Manor House, Bexley, S.O., Kent.

1882. Molesworth, James Murray, Shawclough, near Rochdale: (or care of Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.)

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1885. Monk, Edwin, care of Josiah McGregor, Crown Buildings, 78 Queen Victoria Street, London, E.C.

1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.

1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.

1884. Moore, Benjamin Theophilus, Longwood, Bexley, S. O., Kent.

1876. Moore, Joseph, 1099 Adeline Street, Oakland, San Francisco, California; (or care of Ralph Moore, Government Inspector of Mines, 13 Clairmont Gardens, Glasgow.)

1880. Moreland, Richard, Jun., Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C. [*Expansion, London.*]

1889. Morgan, David John, Central Engineering Works, Cardiff.

1885. Morgan, Thomas Rees, Morgan Engineering Works, Alliance, Ohio, United States.

1887. Morison, Donald Barns, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1888. Morris, Charles, 5 Mangoe Lane, Calcutta, India.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1890. Morris, Francis Sanders, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1890. Morris, John Alfred (*Life Member*). Empire Works, 78 Great Bridgewater Street, Manchester.

1858. Mountain, Charles George, Eagle Foundry, Broad Street, Birmingham.

1886. Mountain, William Charles, Messrs. Ernest Scott and Co., Close Works, Newcastle-on-Tyne; and 9 St. George's Terrace, Jesmond, Newcastle-on-Tyne.

1884. Mower, George A., Crosby Steam Gage and Valve Co., 75 Queen Victoria Street, London, E.C. [*Crosby, London.*]

1885. Mudd, Thomas, Manager, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. Muir, Edwin, 37 Cross Street, Manchester. [1027.]

1876. Muirhead, Richard, Kentish Engineering Works, Maidstone.

1890. Müller, Henry Adolphus, Locomotive Superintendent, Municipal Railway, 3 North Road, Entally, Calcutta, India.

1890. Mumford, Charles Edward, St. Andrew's Works, Bury St. Edmunds.

1890. Munro, John, Merchant Venturers' Technical School, Unity Street, Bristol.

1890. Munro, Robert Douglas, Chief Engineer, Scottish Boiler Insurance and Engine Inspection Co., 13 Dundas Street, Glasgow.

1889. Münster, Bernard Adolph, care of Messrs. Jardine Matheson and Co., Yokohama, Japan.

1890. Murray, Alexander John, Officiating Chief Mechanical Engineer, Government Gun-Carriage Factory, Bombay, India.

1890. Murray, Kenneth Sutherland, Brin's Oxygen Works, 69 Horseferry Road, Westminster, S.W.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1888. Myers, William Beswick (*Life Member*), 14 Victoria Street, Westminster, S.W.

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1889. Nash, Thomas, Sheffield Testing Works, Blonk Street, Sheffield; and Guzerat House, Nether Edge, Sheffield.

1888. Nathan, Adolphus, Messrs. Larini Nathan and Co., Milan; and 15 Via Bigli, Milan, Italy.

1861. Naylor, John William, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1883. Neate, Percy John, 16 The Banks, High Street, Rochester.

1889. Needham, Joseph Edward, Patent Office, 25 Southampton Buildings, London, W.C.

1884. Nelson, John, 48 Bootham, York.

1887. Nelson, Sidney Herbert, Messrs. Samuel Worssam and Co., Oakley Works, King's Road, Chelsea, London, S.W.

1881. Nesfield, Arthur, 7 Rumford Street, Liverpool.

1882. Nettlefold, Hugh, Screw Works, 16 Broad Street, Birmingham. [*Netilefolds, Birmingham.*]

1890. Newton, Percy, Locomotive Department, Great Southern Railway, Buenos Aires, Argentine Republic.

1882. Nicholl, Edward McKillop, Bengal Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Henry S. King and Co., 65 Cornhill, London, E.C.)

1884. Nicholls, James Mayne, Locomotive Superintendent, Nitrate Railways, Iquique, Chili.

1884. Nicholson, Henry, care of G. H. Hill, Albert Chambers, Albert Square, Manchester.

1877. Nicolson, Donald, 16 St. Helen's Place, London, E.C.

1886. Noakes, Thomas Joseph, Messrs. Thomas Noakes and Sons, 35 and 37 Brick Lane, Whitechapel, London, E.

1884. Noakes, Walter Maplesden, 43 York Street, Wynyard Square, Sydney, New South Wales.

1882. Nordenfelt, Thorsten, 9 Victoria Street, Westminster, S.W.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1883. North, Gamble, Messrs. North and Jewel, Peruano Nitrate of Soda and Iodine Works, Iquique, Chile: (or care of John T. North, Avery House, Avery Hill, Eltham.)

1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; Woolpack Buildings, 3 Gracechurch Street, London, E.C.; and Avery House, Avery Hill, Eltham.

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 7 St. Mary's Road, Peckham, London, S.E. [*Oxygen, London.* 8007.]

1888. Norton, William Eardley, 8 Great George Street, Westminster, S.W.

1882. Nunneley, Thomas, 9 Beech Grove Terrace, Leeds.

1885. Oakes, Sir Reginald Louis, Bart., York Engineering Works, Leeman Road, York.

1887. O'Brien, Benjamin Thompson, 45 Fern Grove, Liverpool.

1887. O'Brien, John Owden, Messrs. W. P. Thompson and Co., Ducie Buildings, 6 Bank Street, Manchester.

1890. Ockendon, William, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1868. O'Connor, Charles, 15 Wesley Street, Waterloo, near Liverpool.

1888. O'Donnell, John Patrick, 2 Great George Street, Westminster, S.W.; and Avondale, College Road, Bromley, Kent. [*ODonnell, London.*]

1887. O'Flyn, John Lucius, Messrs. L. and H. Guéret and Co., Exchange, Cardiff.

1889. Ogden, Fred, Patent Office, 25 Southampton Buildings, London, W.C.

1886. Ogle, Percy John, 4 Bishopsgate Street Within, London, E.C.

1875. Okes, John Charles Raymond, 39 Queen Victoria Street, London, E.C. [*Oaktree, London.*]

1882. Orange, James, Messrs. Danby Leigh and Orange, Hong Kong, China: (or care of Mrs. Mary Orange, 2 West End Terrace, Jersey.)

1885. Ormerod, Richard Oliver, 35 Philbeach Gardens, South Kensington, London, S.W.

1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield. [*Osborn, Sheffield.*]

1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.

1889. Owen, Thomas, Midland Railway, Derby.

1886. Owen, Thomas Henry, 200 Newport Road, Cardiff.

1868. Paget, Arthur, Loughborough. [*Paget Company, Loughborough.*]

1877. Panton, William Henry, General Manager, Tees Side Iron and Engine Works, Middlesbrough. [*Teesside, Middlesbrough.*]

1877. Park, John Carter, Locomotive Engineer, North London Railway, Bow, London, E.

1872. Parker, Thomas, Locomotive Carriage and Wagon Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1888. Parker, Thomas, Jun., Locomotive Department, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1879. Parker, William, Chief Engineer Surveyor, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.

1871. Parkes, Persehouse, Messrs. Persehouse Parkes and Co., 21 Drury Buildings, 21 Water Street, Liverpool. [*Fibrous, Liverpool.*]

1884. Parlane, William, Manager, Hong Kong Ice Company, Hong Kong, China.

1886. Parry, Alfred, Messrs. Parry and Co., Vulcan Iron Works, Calcutta, India : (or care of Messrs. J. D. Brown and Co., 5 and 7 Fenchurch Street, London, E.C.)

1889. Parry, Evan Henry, Eagle Chambers, Adelaide Street, Swansea.

1878. Parsons, The Hon. Richard Clere, Oak Lea, Wimbledon Park, Surrey.

1886. Passmore, Frank Bailey, Mansion House Chambers, 11 Queen Victoria Street, London, E.C. [*Knarf, London.*]

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India : (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1881. Patterson, Anthony, Dowlais Iron Works, Dowlais.

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples. [*Pattison, Naples.*]

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester. [*Paxman, Colchester.*]

1880. Peache, James Courthope, Messrs. Willans and Robinson, Ferry Works, Thames Ditton.

1890. Peacock, Francis, Locomotive Superintendent, Smyrna and Cassaba Railway, Smyrna, Asia Minor.

1890. Peacock, James Albert Wells, Assistant Locomotive Superintendent, Smyrna and Cassaba Railway, Smyrna, Asia Minor.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Pearce, George Cope, Ryefields, Ross.

1873. Pearce, Richard, Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India.

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1885. Pearson, Henry William, Engineer, Bristol Water Works, Small Street, Bristol.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1883. Peck, Walter, Government Inspector of Machinery, Auckland, New Zealand: (or care of Messrs. J. H. Peck and Co., Wallgate, Wigan.)

1888. Peel, Charles Edmund, Quay Parade, Swansea.

1884. Penn, George Williams, Lloyd's Bute Proving House, Cardiff.

1873. Penn, John, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1861. Perkins, Loftus, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.

1879. Perkins, Stanhope, Healey Terrace, Fairfield, near Manchester.

1882. Perry, Alfred, Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham.

1890. Perry, Weston Alcock, Phosphor-Bronze Co., Birmingham; and Kenwood, St. Peter's Road, Birmingham.

1882. Petherick, Vernon, Messrs. Petherick and Co., Elevator and Hydraulic Engineers, Box 1046, General Post Office, Sydney, New South Wales.

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1885. Phillips, Charles David, Emlyn Engineering Works, Newport, Monmouthshire. [*Machinery, Newport, Mon.*]

1885. Phillips, Henry Parnham, District Locomotive Superintendent, Eastern Bengal State Railway, Calcutta, India.

1878. Phillips, John, 4 Corona Road, Burnt Ash Hill, Lee, London, S.E.

1885. Phillips, Lionel, Mining Engineer, Bultfontein Diamond Mine, Kimberley, South Africa; and care of H. Eckstein, Box 149, Johannesburg, Transvaal, South Africa.

1879. Phillips, Robert Edward, Royal Courts Chambers, 70 and 72 Chancery Lane, London, W.C.; and Rochelle, Selhurst Road, South Norwood, London, S.E. [*Phicycle, London.*]

1890. Phillips, Walter, 108 Fenchurch Street, London, E.C.

1882. Phipps, Christopher Edward, Deputy Locomotive Superintendent, Madras Railway, Perambore Works, Madras.

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham. [*Piercy, Birmingham.* 20.]

1877. Pigot, Thomas Francis, Professor of Engineering, Royal College of Science for Ireland, Dublin.

1888. Pilkington, Herbert, Midland Coal Coke and Iron Co., Apedale, near Newcastle, Staffordshire.

1883. Pillow, Edward, London and North Western Railway, Locomotive Department, Crewe.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France. [*Lethuillier Pinel, Rouen.*]

1888. Pirrie, Norman, Ellerslie, Ryton-on-Tyne, R.S.O., Co. Durham.

1888. Pirrie, William James, Messrs. Harland and Wolff, Belfast.

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath. [*Stothert, Bath.*]

1887. Place, John, Jun., Linotype Co., 11 Hulme Street, Oxford Road, Manchester.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1883. Platt, James Edward, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel [Radcliffe (*Life Member*), Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia.

1869. Player, John, Clydach Foundry, near Swansea.

1888. Pogson, Joseph, Manager and Engineer, Huddersfield Corporation Tramways, Huddersfield.

1890. Poke, George Henry, Chief Engineer, Government Gun-Carriage Factory, Colaba, Bombay, India; and 9 Hilda Road, North Brixton, London, S.W.

1886. Pollock, James, Fenchurch House, 5 and 7 Fenchurch Street, London, E.C. [*Specific, London.*]

1876. Pollock, Julius Frederick Moore, Messrs. Pollock and Pollock, Longelose Works, Newtown, Leeds.

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool. [*Pooley, Liverpool.*]

1890. Potter, William Henry, 32 Pelham Street, Nottingham.

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C.; and 117 Camberwell Grove, London, S.E.

1878. Powell, Henry Coke, 23 Rue St. Julien, Rouen, France: (or care of C. M. Roffe, 1 Bedford Row, London, W.C.)

1890. Powell, James Richard, Pierhead Chambers, Cardiff.

1870. Powell, Thomas (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1874. Powell, Thomas (Nephew), Brynhyfryd, Neath.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1885. Pratten, William John, Messrs. Harland and Wolff, Belfast.

1890. Preece, William Henry, F.R.S., General Post Office, St. Martin's-le-Grand, London, E.C.

1882. Presser, Ernest Charles Antoine, 4 Salesas, Madrid.

1856. Preston, Francis, Netherfield House, Kirkburton, near Huddersfield.

1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 52 Queen Victoria Street, London, E.C. [*Indices, London.* 1533.]

1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow; and 6 Osborne Villas, Jesmond, Newcastle-on-Tyne.

1890. Price, John, Inspecting Engineer, Workington.

1889. Price, John Bennett, Messrs. Stevenson and Co., Canal Foundry, Preston.

1859. Price-Williams, Richard, 4 Victoria Mansions, 32 Victoria Street, Westminster, S.W. [*Spandrel, London.*]

1886. Price-Williams, Seymour William, 3 Westminster Chambers, 5 Victoria Street, Westminster, S.W. [*Spandrel, London.*]

1874. Prosser, William Henry, Messrs. Harfield and Co., Blaydon-on-Tyne.

1885. Pudan, Oliver, Chief Engineer's Office, Cambria Iron Works, Johnstown, Pennsylvania, U.S.: (or 15 Princes Street, Yeovil.)

1890. Pugh, Charles Henry, Whitworth Works, Rea Street South, Birmingham.

1884. Puplett, Samuel, 5 Thornbury Road, Clapham Park, London, S.W.

1866. Putnam, William, Darlington Forge, Darlington.

1887. Pyne, Thomas Salter, care of H.H. the Ameer of Afghanistan, Cabul; care of Messrs. Walsh Lovett and Co., Calcutta, India.

1870. Radcliffe, William, Camden House, 25 Collegiate Crescent, Sheffield.

1878. Radford, Richard Heber, 15 St. James' Row, Sheffield. [*Radford, Sheffield.*]

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1884. Rafarel, William Claude, Barnstaple Foundry and Engineering Works, Victoria Road, Barnstaple. [*Rafarel, Barnstaple.*]

1885. Rainforth, William, Jun., Britannia Iron Works, Lincoln. [*Rainforths, Lincoln.*]

1878. Rait, Henry Milnes, Messrs. Rait and Gardiner, 155 Fenchurch Street, London, E.C. [*Repairs, London.*]

1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.

1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness; and Reform Chambers, 105 Pall Mall, London, S.W.

1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W. [*Ransome, London.*]

1886. Ransome, James Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich. [*Ransomes, Ipswich.*]

1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich. [*Waterside, Ipswich.*]

1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, 9 Victoria Street, Westminster, S.W. [*Ransomes, Westminster.*]

1888. Rapley, Frederick Harvey, Messrs. J. E. and M. Clark and Co., Dashwood House, London, E.C.

1889. Ratcliffe, James Thomas, Fabric von Izr. K. Poznanski, Lodz, Russian Poland.

1883. Rathbone, Edgar Philip, Wehl's Buildings, Johannesburg, Transvaal, South Africa.

1867. Ratliffe, George, 81 Cannon Street Buildings, 139 Cannon Street, London, E.C.

1862. Ravenhill, John R., Delaford, Iver, near Uxbridge.

1872. Rawlins, John, Manager, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham. [*Metro, Birmingham.*]

1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.

1887. Readhead, Robert, Messrs. John Readhead and Co., West Docks, South Shields.

1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada. [*Redpath, Montreal.*]

1883. Reed, Alexander Henry, 64 Mark Lane, London, E.C. [*Wagon, London.*]

1870. Reed, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W. [*Carnage, London.*]

1884. Rees, William Thomas, Mining Engineer, Gadlys Cottage, Aberdare.

1890. Reeves, Frank, Assistant Engineer, Ferro Carril de Buenos Aires al Pacifico, 228 Calle Piedad, Buenos Aires, Argentine Republic.

1883. Reid, James, Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1889. Rendell, Alan Wood, Locomotive Carriage and Wagon Superintendent, Eastern Bengal State Railway, Kanchrapara, Bengal, India: (or Ravenswood, Byculla Park, Enfield.)

1890. Rendell, Samuel, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and 306 Fairfield Road, Fairfield, near Manchester.

1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.

1879. Rennie, John Keith, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields. [*Rennoldson, South Shields.* 11.]

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1883. Reunert, Theodore, Box 209, Kimberley, South Africa; Box 92, Johannesburg, Transvaal, South Africa: (or care of Messrs. Findlay Durham and Brodie, 61 St. Mary Axe, London, E.C.)

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1879. Reynolds, George Bernard, Assistant Manager, Wardha Coal State Railway, Warora, Central Provinces, India; care of Messrs. Grindlay Groom and Co., Bombay, India.

1882. Rhodes, Vincent, Manager, Messrs. Hudson Brothers, Clyde Engineering Works, Granville, near Sydney, New South Wales: (or care of Mrs. E. A. Rhodes, 5 Ainger Terrace, St. Catherine's Road, Grantham.)

1890. Rice, Thomas Sydney, Messrs. Harvey Graham and Co., 10 Bush Lane, Cannon Street, London, E.C.

1866. Richards, Edward Windsor, Low Moor Iron Works, near Bradford.

1882. Richards, George, Messrs. George Richards and Co., Atlantic Works, Broadheath, near Manchester. [*Richards, Altrincham.*]

1884. Richards, Lewis, West Cumberland Iron and Steel Works, Workington; and Derwent View, Workington.

1863. Richardson, The Hon. Edward, C.M.G., Wellington, New Zealand.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1887. Richardson, Thomas, Jun., Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1884. Riches, Charles Hurry, Assistant Locomotive Superintendent, Taff Vale Railway, Cardiff.

1890. Riches, Glenford Mitchell, Fish Dock, Grimsby.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff. [*Locomotive, Cardiff.*]

1889. Richmond, Joseph, New Sun Iron Works, Burdett Road, Bow, London, E.; and 30 Kirby Street, Hatton Garden, London, E.C.

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland. [*Rickaby, Sunderland.*]

1879. Ridley, James Cartmell, Swalwell Steel Works, Newcastle-on-Tyne.

1887. Rickie, John, District Locomotive Superintendent, North Western Railway, Quetta, Beluchistan, India.

1874. Riley, James, General Manager, Steel Company of Scotland, 150 Hope Street, Glasgow.

1884. Ripper, William, Professor of Mechanical Engineering, The Technical School, St. George's Square, Sheffield.

1889. Riva, Enrico, Locomotive and Carriage Superintendent, Rete Adriatica, Ferrovie Meridionale, Florence, Italy.

1879. Rixom, Alfred John, 1 Gordon Villas, Park Road, Loughborough.

1887. Roberts, Thomas, Locomotive Engineer, Government Railways, Adelaide, South Australia.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Detroit, Michigan, United States.

1887. Roberts, William, Argentine Great Western Railway, Mendoza, Argentine Republic.

1879. Robertson, William, Messrs. Boyd and Co., Engineers and Shipbuilders, Shanghai, China: (or care of Herbert J. Stockton, 16 Philpot Lane, London, E.C.)

1883. Robins, Edward, 105 Regent Street, London, W.

1890. Robinson, Frederick Arthur, Messrs. Howard Farrar and Co., 69 Cornhill, London, E.C.

1874. Robinson, Henry, Professor of Surveying and Civil Engineering, King's College, Strand, London, W.C.; and 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.

1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and Westwood Hall, Leek, near Stoke-upon-Trent.

1886. Robinson, John, Barry Dock and Railways, Barry, near Cardiff.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow.

1890. Robinson, Sydney Jessop, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1866. Robson, Thomas, Mining Engineer, Lumley Thicks, Fence Houses.

1890. Rochford, John, Commissioners of Irish Lights, Westmoreland Street, Dublin.

1888. Rock, John William, Kent Street, Sydney, New South Wales.

1879. Rodger, William, care of Messrs. C. H. B. Forbes and Co., 3 Elphinstone Circle, Bombay: (or care of Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.)

1884. Rodrigues, José Maria de Chermont, Rua de S. Pedro 54 sobrado, Rio de Janeiro, Brazil: (or care of Messrs. Jacob Walter and Co., Billiter Square Buildings, London, E.C.)

1872. Rofe, Henry, 8 Victoria Street, Westminster, S.W.

1885. Rogers, Henry John, Watford Iron Works, Watford. [*Engineer, Watford.*]

1871. Rollo, David, Messrs. David Rollo and Sons, Fulton Engine Works, 10 Fulton Street, Liverpool.

1889. Rosenthal, James Hermann, Babcock and Wilcox Boiler Co., 114 Newgate Street, London, E.C.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1856. Rouse, Frederick, Locomotive Department, Great Northern Railway, Peterborough.

1878. Routh, William Pole, 25 Rua de S. Francisco, Oporto, Portugal: (or care of Cyril E. Routh, St. Michael's House, Cornhill, London, E.C.)

1888. Rowan, James, Messrs. David Rowan and Son, Elliot Street, Glasgow.

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 6 Onslow Gardens, South Kensington, London, S.W. [*Ruston, Lincoln.*]

1884. Rutherford, George, General Manager, Wallsend Pontoon Works, Bute Docks, Cardiff. [*Wall, Cardiff.*]

1877. Rutter, Edward, Hotham House, Heron Court, Richmond, Surrey.

1885. Ryan, John, D.Sc., Professor of Physics and Engineering, University College, Bristol.

1883. Ryder, George, Turner Bridge Iron Works, Tong, near Bolton. [*Ryder, Machinist, Tong, Bolton.* 33A.]

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C. [*Sextant, London.* 1668.]

1883. Sadoine, Baron Eugène, 13 Place de Bronckart, Liége, Belgium.

1864. Saïd, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 9 Park Crescent, Portland Place, London, W.)

1859. Salt, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford; and 23 St. Ermin's Mansions, Westminster, S.W.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N. [*Bascule, London.* 6699.]

1865. Samuelson, Sir Bernhard, Bart., M.P., F.R.S., Britannia Iron Works, Banbury; 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1890. Sandberg, Christer Peter, 19 Great George Street, Westminster, S.W.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and Elm Lodge, Southall.

1871. Sanders, Richard David, Hartfield House, Eastbourne.

1886. Sandford, Horatio, Messrs. E. A. and H. Sandford, Thames Iron Works, Gravesend.

1881. Sandiford, Charles, Locomotive and Carriage Superintendent, North Western Railway, Lahore, Punjaub, India.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W. [*Sovez, London.* 3133.]

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.*]; and Cold Harbour Lawn, Wivelsfield, near Burgess Hill, S.O., Sussex.

1869. Scarlett, James, Messrs. E. Green and Son, 14 St. Ann's Square, Manchester.

1890. Schofield, George Andrew, Assistant Locomotive and Carriage Superintendent, State Railways, Chili.

1886. Scholes, William Henry, 1255 n/n Rivadavia, Buenos Aires, Argentine Republic: (or care of George Scholes, 79 Mark Lane, London, E.C.)

1883. Schönheyder, William, 4 Rosebery Road, Brixton, London, S.W.

1880. Schram, Richard, 17A Great George Street, Westminster, S.W. [*Schram, London.*]

1890. Schroller, William, Luhrig Coal and Ore Dressing Appliances Co., 4 Victoria Mansions, 32 Victoria Street, Westminster, S.W.

1886. Schurr, Albert Ebenezer, Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Lyncot, Romford.

1885. Scorgie, James, Professor of Applied Mechanics, Civil Engineering College, Poona, India: 20 Loanhead Terrace, Aberdeen: (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.)

1882. Scott, Charles Herbert, Messrs. Summers and Scott, High Orchard Iron Works, Gloucester.

1890. Scott, Frederick McClure, 89 Victoria Street, Liverpool.

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport. [*Atlas, Reddish.*]

1881. Scott, George Innes, Three Indian King's Court, Quayside, Newcastle-on-Tyne.

1877. Scott, Irving M., Union Iron Works, San Francisco, California.

1881. Scott, James, Umlaas Wool-Scouring Works, Durban, Natal: (or Douglasfield, Murthly, Perthshire.)

1886. Scott, James, Consett Iron Works, Consett, R.S.O., County Durham.

1885. Scott, Robert, 35 Queen Victoria Street, London, E.C. [*Chisaiscot, London.*]

1861. Scott, Walter Henry, Locomotive Superintendent, Great Southern Railway, Buenos Aires, Argentine Republic; (or care of H. Eaton, 75 Tulse Hill, London, S.W.)

1884. Scott-Moncrieff, William Dundas, 86 Newman Street, Oxford Street, London, W.

1868. Scriven, Charles, Whinfield Mount, Chapel Allerton, Leeds. [*Scriven, Leeds.*]

1882. Seabrook, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay.

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1864. Seddon, John, 98 Wallgate, Wigan.

1886. Seddon, Robert Barlow, Manager, Wigan Wagon Works, Wigan.

1882. Selfe, Norman, 279 George Street, Sydney, New South Wales.

1884. Sellers, Coleman, E.D., Professor of Engineering, Stevens Institute, and Franklin Institute; 3301 Baring Street, Philadelphia, Pennsylvania, United States; and International Niagara Commission, Central Institution, Exhibition Road, London, S.W.

1888. Sellers, George, Holly Cottage, Wakefield.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1889. Selman, David Codrington, Professor of Mathematics, University College, Bristol.

1881. Sennett, Richard, Messrs. Maudslay Sons and Field, Lambeth, London, S.E.

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.

1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Howrah Iron Works, Howrah, Bengal; 7 Hastings Street, Calcutta; and care of William Roberts, 44 Breeze Hill, Bootle, Liverpool.

1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1881. Shapton, William, Sir William G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1890. Shardlow, Ambrose, Ealing Works, Washford Road, Attercliffe, Sheffield.

1875. Sharp, Thomas Budworth, Chief Engineer and Works Manager, Muntz Metal Works, Birmingham.

1882. Sharrock, Samuel Lord, New South Wales Club, Sydney, New South Wales.

1879. Shaw, Henry Selby Hele, Professor of Engineering, University College, Liverpool.

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1881. Shaw, William, Messrs. W. Shaw Kirtley and Co., Wellington Cast Steel Foundry, Middlesbrough.

1890. Sheldon, Harry Cecil, Messrs. W. P. Thompson and Boult, 63 Long Row, Nottingham.

1856. Shelley, Charles Percy Bysshe, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1875. Sheppard, Herbert Gurney, Resident Engineer, Lake Aboukir Reclamation Works, near Alexandria, Egypt; care of R. Lang Anderson, Schutz Station, Ramleh, Alexandria, Egypt: (or 89 Westbourne Terrace, Hyde Park, London, W.)

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1888. Shin, Tsuneta, Director, Ishikawajima Shipbuilding and Engineering Co., Tokyo, Japan.

1889. Shone, Isaac, Great George Street Chambers, Westminster, S.W.

1890. Shoosmith, Harry, Messrs. G. Kynoch and Co., Lion Works, Witton, Birmingham.

1890. Shore, Alfred Thomas, Government Inspector of Steam Boilers, Custom House, Bombay, India.

1885. Shuttleworth, Alfred, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln. [*Claytons, Lincoln.*]

1885. Shuttleworth, Major Frank, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and Old Warden Park, Biggleswade. [*Claytons, Lincoln.*]

1888. Siemens, Frederick, 10 Queen Anne's Gate, Westminster, S.W.

1888. Siemens, Dr. Werner, Messrs. Siemens and Halske, 94 Markgrafen Strasse, Berlin.

1871. Simon, Henry, 20 Mount Street, Manchester. [*Reform, Manchester.*]

1877. Simonds, William Turner (*Life Member*), Messrs. J. C. Simonds and Son, Oil Mills, Boston.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1885. Simpson, James Thomas, Executive Engineer, Public Works Department, Shwebo, Upper Burmah.

1882. Simpson, John Harwood, Manchester Ship Canal, 65 King Street, Manchester.

1889. Sinclair, Nisbet, Messrs. Robert Napier and Sons, Lancefield House, Glasgow.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C. [*Sinclair, London.*]

1857. Sinclair, Robert Cooper, 3 Adelaide Place, London Bridge, London, E.C.

1881. Sisson, William, Quay Street Iron Works, Gloucester. [*Sisson, Gloucester.*]

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, 25 Royal York Crescent, Clifton, Bristol.

1885. Slight, William Hooper, Netherlands Indian Steamship Co., Soerabaya, Java: (or Woodborough Vicarage, Nottingham.)

1886. Small, James Miln, Messrs. Urquhart and Co., 11 Victoria Street, Westminster, S.W.

1889. Smelt, John Dann, Argentine Great Western Railway, 4 Finsbury Circus, London, E.C.

1879. Smith, Allison Dalrymple, Assistant Locomotive Superintendent, Locomotive Workshops, Victorian Railways, Newport, Victoria.

1879. Smith, Charles Hubert, Engineer and Shipwright Surveyor to the Board of Trade, North Shields.

1866. Smith, Edward Fisher, 34 Avenue Road, Regent's Park, London, N.W.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill; and Summerhill, Kingswinford, near Dudley. [*Fencing, Brierley Hill.*]

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, Sir John, Parkfield, Duffield Road, Derby.

1876. Smith, John, Wintoun Terrace, Rochdale.

1883. Smith, John Bagnold, Newstead Colliery, near Nottingham.

1890. Smith, John Windle, Messrs. Marshall Sons and Co., and Messrs. Walsh Lovett and Co., 308 Calle Peru, Buenos Aires, Argentine Republic.

1857. Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness; and Rhine Hill, Stratford-on-Avon.

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax; and 18 Abingdon Street, Westminster, S.W. [*Outfall, London.*]

1886. Smith, Reginald Arthur, Messrs. Dorman and Smith, 24 Brazennose Street, Manchester.

1881. Smith, Robert Henry, Professor of Engineering, Mason Science College, Birmingham; and 124 Hagley Road, Edgbaston, Birmingham.

1885. Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds. [*Tomsmith, Leeds.*]

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne. [*Wasteneys Smith, Newcastle-on-Tyne.* 429.]

1890. Smith, William, London and Manchester Plate Glass Co., Sutton, St. Helen's, Lancashire.

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1887. Smith, William Mark, District Locomotive Carriage and Wagon Superintendent, Great Southern and Western Railway, Cork.

1882. Smyth, James Josiah, Messrs. James Smyth and Sons, Peasenhall, Suffolk.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

1883. Snelus, George James, F.R.S., Ennerdale Hall, Frizington, near Carnforth.

1885. Snowdon, John Armstrong, Stanners Closes Steel Works, Wolsingham, near Darlington.

1878. Sopwith, Thomas, Mining Engineer, 6 Great George Street, Westminster, S.W. [*Sopwith, London.* 3175.]

1887. Sorabji, Shapurji, Bombay Foundry and Engine Works, Khetwady, Bombay: (or care of Messrs. S. and E. Ransome and Co., 10 Essex Street, Strand, London, W.C.)

1884. Soulsby, James Charlton, 17 Mount Stuart Square, Cardiff.

1889. Souter-Robertson, David, Assistant Superintendent, Government Canal Foundry and Workshops, Roorkee, North Western Provinces, India.

1885. Southwell, Frederick Charles, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1877. Soyres, Francis Johnstone de, 4 Arlington Villas, Clifton, near Bristol.

1887. Spence, William, Cork Street Foundry and Engineering Works, Dublin.

1887. Spencer, Alexander, 77 Cannon Street, London, E.C.

1878. Spencer, Alfred G., Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1877. Spencer, John, Globe Tube Works, Wednesbury [*Tubes, Wednesbury.*]; and 3 Queen Street Place, Cannon Street, London, E.C. [*Tubes, London.*]

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1885. Spencer, Mountford, Messrs. Luke and Spencer, Ardwick, Manchester; and The Meadows, Alderley Edge, near Manchester.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1885. Spooner, George Percival, Locomotive Superintendent, Bolan Railway, Hirokh, Beluchistan, India; and Bron-y-garth, Portmadoc, R.S.O., Carnarvonshire.

1883. Spooner, Henry John, 309 Regent Street, London, W.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, Chemical Laboratory and Testing Works, Broadway, Westminster, S.W.

1888. Stanley, Harry Frank, Messrs. Pontifex and Wood, Farringdon Works, Shoe Lane, London, E.C.; and 84 Finsbury Park Road, London, N.

1888. Stannah, Joseph, 20 Southwark Bridge Road, London, S.E.

1884. Stanton, Frederic Barry, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.

1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W. [*Precursor, London.*]

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, London, E.C. [*Fluvius, London.*]

1888. Stephenson-Peach, William John, Trent Fish Culture Co., Milton, Burton-on-Trent.

1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow [*Crown, Glasgow.*]; and 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W. [*Elsterne, London.* 3066.]

1887. Stevenson, David Alan, F.R.S.E., 84 George Street, Edinburgh.

1877. Stewart, Alexander, Manager, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.

1887. Stewart, Andrew, 41 Oswald Street, Glasgow.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow. [*Stewart, Glasgow.* 531.]

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E. [*Steamships, London.*]

1888. Stiff, William Charles, Credenda Seamless Steel-Tube Works, Ledsam Street, Birmingham.

1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford, Kent.

1885. Stirling, Matthew, Locomotive Superintendent, Hull Barnsley and West Riding Junction Railway and Dock Co., Hull.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1888. Stirling, Robert, Locomotive Department, North Eastern Railway, Gateshead.

1875. Stoker, Frederick William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S.O., Kent.

1877. Stokes, Alfred Allen, Elmcote, Godalming.

1887. Stone, Frank Holmes, P.O. Box, Kingston, Jamaica: (or West Point, Slade Lane, Levenshulme, Manchester.)

1877. Stothert, George Kelson, Steam Ship Works, Bristol.

1888. Strachan, James, Manager, Fundição Bowman, Pernambuco, Brazil.

1888. Straker, Sidney, 240 Stanstead Road, Forest Hill, London, S.E.

1884. Stronge, Charles, Locomotive Department, Porto Alegre and New Hamburg Railway, São Leopoldo, Rio Grande do Sol, Brazil: (or 1 Albion Street, Hyde Park, London, W.)

1873. Strype, William George, 1 College Street, Dublin. [*Strype, Dublin.*]

1878. Stuart, Professor James, M.P., 24 Grosvenor Road, London, S.W.

1889. Stuart-Hartland, Dare Arthur, Messrs. Balmer Lawrie and Co., 103 Clive Street, Calcutta, India.

1882. Sturgeon, John, Shrublands, Hoole Road, Chester.

1890. Stutzer, Waldemar, Koltchugin Brass and Copper Mill Co., Alexandrov Station, Jaroslav Railroad, Russia.

1882. Sugden, Thomas, Chadderton Iron Works, Irk Vale, Chadderton, near Oldham; and 10 Mark Lane, London, E.C.

1890. Sulzer, Jacob, Messrs. Sulzer Brothers, Winterthur, Switzerland.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1883. Sutton, Joseph Walker, Messrs. Willans and Robinson, Ferry Works, Thames Ditton, Surrey.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1887. Suverkrop, John Peter, 1 Kew Gardens Road, Kew, Surrey.

1882. Swaine, John, Messrs. Wright Butler and Co., Panteg Steel Works, near Newport, Monmouthshire.

1884. Swan, Joseph Wilson, 57 Holborn Viaduct, London, E.C.; and Lauriston, Bromley, Kent.

1882. Swinburne, William, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.

1864. Swindell, James Swindell Evers, Clent House, Stourbridge.

1890. Swinerd, Edward, Superintendent, Locomotive Carriage and Wagon Departments, Mogyana Railway, Campinas, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, Laurence Pountney Hill, London, E.C.)

1890. Swinnerton, Robert Allen William, Executive Engineer, Public Works Department, Ellichpore, Berar, India.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and The Corner House, Shortlands, S.O., Kent.

1882. Tandy, John O'Brien, London and North Western Railway, Locomotive Department, Crewe; and 4 Wellington Villas, Wellington Square, Crewe.

1875. Tangye, George, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1861. Tangye, James, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.

1876. Taunton, Richard Hobbs, Messrs. Taunton Delmard Lane and Co., Star Tube Works, Heneage Street, Birmingham. [*Taunton, Birmingham.*]

1882. Tayler, Alexander James Wallis, 77 Victoria Road, Kilburn, London, N.W.

1874. Taylor, Arthur, Manager, Lahat Tin Mines, Perak, viâ Penang; and 6 Queen Street Place, Upper Thames Street, London, E.C.

1887. Taylor, James, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1874. Taylor, Percyvale, Messrs. Burthe and Taylor, 26 Rue de Caumartin, Paris.

1882. Taylor, Robert Henry, 55 Kent House Road, Sydenham, London, S.E.

1882. Taylor, Thomas Albert Oakes, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.

1864. Tennant, Sir Charles, Bart. (*Life Member*), The Glen, Innerleithen, near Edinburgh.

1882. Terry, Stephen Harding, Stafford House, Hednesford, near Stafford.

1877. Thom, William, Messrs. Yates and Thom, Canal Foundry, Blackburn.

1889. Thomas, James Donnithorne, 25A Old Broad Street, London, E.C.

1867. Thomas, Joseph Lee, 2 Hanover Terrace, Ladbroke Square, Notting Hill, London, W.

1888. Thomas, Philip Alexander, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Argument, London.*]

1864. Thomas, Thomas, 10 Richmond Road, Roath, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.

1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.

1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.

1880. Thompson, Thomas William, Eastham Ferry Pier, near Birkenhead.

1887. Thompson, William Phillips, 6 Lord Street, Liverpool.

1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]

1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]

1889. Thomson, Robert McNidar, Yokohama Engine and Iron Works, Kobe, Japan.

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1885. Thornley, George, Messrs. Buxton and Thornley, Waterloo Engineering Works, Burton-on-Trent.

1877. Thornton, Frederic William, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1882. Thornton, Hawthorn Robert, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1888. Thornton, Robert Samuel, West's Patent Press Co., Etawah, North Western Provinces, India.

1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W. [*Thornycroft, London.*]

1882. Thow, William, Locomotive Engineer, New South Wales Government Railways, Eveleigh Workshops, Sydney, New South Wales: (or care of Joseph Meilbek, 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.)

1884. Thwaites, Arthur Hirst, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford. [*Thwaites, Bradford.* 325.]

1887. Thwaites, Edward Hirst, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford.

1885. Timmermans, François, Managing Director, Société anonyme des Ateliers de la Meuse, Liége, Belgium. [*Société Meuse, Liége.*]

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W. [*Timmis, London.*]

1886. Tipping, Henry, 38 Croom's Hill, Greenwich, London, S.E.

1890. Titley, Arthur, Messrs. Samuel Fisher and Co., Nile Foundry, Sheepcote Street, Birmingham.

1888. Todd, Robert Ernest, Mechanical Engineer, La Madrid, Ferro Carril National Central Norte, Argentine Republic: (or care of William H. Todd, County Buildings, Land of Green Ginger, Hull.)

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1857. Tomlinson, Joseph, 64 Priory Road, West Hampstead, London, N.W.

1888. Topple, Charles James, Machinery Department, Royal Arsenal, Woolwich.

1883. Tower, Beauchamp, 5 Queen Anne's Gate, Westminster, S.W.

1889. Towler, Alfred, Messrs. Hathorn Davey and Co., Sun Foundry, Leeds.

1886. Towne, Henry Robinson, Yale and Towne Manufacturing Co., Stamford, Connecticut, United States.

1890. Trail, John, Swansea Dry Docks and Engineering Co., Swansea.

1888. Travis, Henry, Machinery Department, Royal Arsenal, Woolwich.

1889. Trenerry, William Penrose, 21 Via Cavour, Florence, Italy. [*Trenerry, Firenze.*]

1883. Trentham, William Henry, 2 Hervey Road, Shooter's Hill Road, London, S.E.

1876. Trevithick, Richard Francis, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Mrs. Mary Trevithick, The Cliff, Penzance.)

1886. Trew, James Bradford, High Street, Watford, Herts.

1887. Trier, Frank, Messrs. Brunton and Trier, 19 Great George Street, Westminster, S.W.

1885. Trueman, Thomas Brynalyn, Ferro Carril Buenos Aires al Pacifico, Junin, Argentine Republic: (or care of Thomas R. Trueman, 3 The Barons, Twickenham.)

1887. Turnbull, Alexander, Messrs. Alexander Turnbull and Co., St. Mungo Works, Bishopbriggs, Glasgow.

1885. Turnbull, John, Jun., 255 Bath Street, Glasgow. [*Turbine, Glasgow.*]

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

1886. Turner, George Reynolds, Vulcan Iron Works, Langley Mill, near Nottingham; and 81 Highgate Road, London, N.W.

1887. Turner, Joshua Alfred Alexander, Superintendent and Chief Engineer, Government Steam Flour Mills, Poona, India.

1882. Turner, Thomas, New British Iron Works, Corngreaves, near Birmingham.

1886. Turner, Tom Newsum, Vulcan Iron Works, Langley Mill, near Nottingham.

1876. Turney, Sir John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham. [*Turney, Nottingham.*]

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1856. Tyler, Sir Henry Whatley, K.C.B., M.P., Pymmes Park, Edmonton, Middlesex.

1877. Tylor, Joseph John, 2 Newgate Street, London, E.C.

1889. Tyrrell, Joseph John, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1878. Tyson, Isaac Oliver, Ousegate Iron Works, Selby.

1878. Unwin, William Cawthorne, F.R.S., Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W. and 7 Palace Gate Mansions, Kensington, London, W.

1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Tamboff Government, Russia.

1880. Valon, William Andrew McIntosh, Connaught Mansions, Victoria Street, Westminster, S.W.; and Ramsgate. [*Valon, Ramsgate.*]

1885. Vaughan, William Henry, Royal Iron Works, West Gorton, Manchester. [*Pulleys, Openshaw.*]

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.; and Rothbury, Blackheath Park, London, S.E. [*Exemplar, London.*]

1889. Vesian, John Stuart Ellis de, 5 Crown Court, Cheapside, London, E.C. [*Biceps, London.*]

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1888. Voysey, Henry Wesley, 1 Fordwych Road, Brondesbury, London, N.W.

1883. Waddell, James, Superintending Engineer, Netherlands India Steam Navigation Co., Soerabaya, Java; and 13 Austin Friars, London, E.C.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1879. Wadia, The Hon. Nowrosjee Nesserwanjee, C.I.E., Manager, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.) [*Wadia, Tardeo, Bombay.*]

1882. Wailes, George Herbert, St. Andrews, Watford, Herts.

1875. Wailes, John William, Calderbank Steel and Coal Co., Calderbank, near Airdrie; and Monkland House, near Airdrie.

1884. Wailes, Thomas Waters, General Manager, Mountstuart Dry Dock and Engineering Works, Cardiff. [*Mountstuart, Cardiff.*]

1888. Waister, William Henry, Assistant Locomotive Superintendent, Great Western Railway, Stafford Road Works, Wolverhampton.

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1882. Wakefield, William, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Grand Canal Street, Dublin.

1890. Walkeden, George Henry, Temperance Life Buildings, Swanston Street, Melbourne, Victoria.

1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds. [*Tannett Walker, Leeds.*]

1877. Walker, David, Superintendent of Engineering Workshops, King's College, Strand, London, W.C.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1890. Walker, Henry, Messrs. C. A. Parsons and Co., Heaton Works, Newcastle-on-Tyne; and 37 Heaton Grove, Newcastle-on-Tyne.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 3 Alexandra Road, Southport. [*Pagefield, Wigan.*]

1884. Walker, Matthew, 16 London Street, Fenchurch Street, London, E.C.

1886. Walker, Robert John, Church-Stile House, Shap, R.S.O., Westmoreland.

1884. Walker, Sydney Ferris, 195 Severn Road, Cardiff [*Dynamo, Cardiff.*]; and Hunter's Forge, New Bridge Street, Newcastle-on-Tyne. [*Dynamo, Newcastle-on-Tyne.*]

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1878. Walker, William, Kaliemaas, Alleyne Park, West Dulwich, London, S.E. [*Bromo, London.*]

1890. Walker, William George, University College, Bristol.

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1881. Walkinshaw, Frank, Yokohama Water Works and Harbour Works, Yokohama, Japan: (or care of W. Walkinshaw, Hartley Grange, Winchfield.)

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1884. Wallau, Frederick Peter, Messrs. Harland and Wolff, Belfast.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1877. Walton, James, 28 Maryon Road, Charlton.

1881. Warburton, John Seaton, 49 New Road, Grays, S.O., Essex; and 19 Stanwick Road, West Kensington, London, W.

1882. Ward, Thomas Henry, Melrose Villa, Church Road, Smethwick, near Birmingham.

1876. Ward, William Meese, Limerick Foundry, Great Bridge, Tipton.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham. [*Bolts, Birmingham.*]

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1885. Warren, Henry John, Jun., Lynton Villa, Camborne: (or Hayle, Cornwall.)

1885. Warren, William, care of Messrs. Jardine Matheson and Co., Hong Kong, China: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.)

1882. Warsop, Henry, Clarendon Hotel, Nottingham.

1889. Warsop, Thomas, Coniston Copper Mines, Coniston, S.O., Lancashire.

1858. Waterhouse, Thomas (*Life Member*), Claremont Place, Sheffield.

1881. Watkins, Alfred, 2 Westcombe Park Road, Blackheath, London, S.E.

1862. Watkins, Richard, 71 Blenheim Crescent, London, W.

1890. Watkinson, William Henry, Central Higher Board School, Orchard Lane, Sheffield.

1890. Watson, George Coghlan, Manganese Bronze and Brass Co., St. George's Wharf, Deptford, London, S.E.; and 1 Farquharson Road, Croydon.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne. [*Watsons, Newcastle-on-Tyne.* 439.]

1879. Watson, William Renny, Messrs. Mirrlees Tait and Watson, Glasgow.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1886. Weatherburn, Robert, Locomotive Manager, Midland Railway Works, Kentish Town, London, N.W.

1884. Webb, Richard George, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India: (or care of Francis Webb, 31 Southampton Buildings, Chancery Lane, London, E.C.).

1890. Webster, John James, 67 Lord Street, Liverpool.

1887. Webster, William, care of Messrs. J. M. Lyon and Co., Engineers, Singapore.

1883. Weck, Friedrich, Cambridge Buildings, John Bright Street, Birmingham.

1888. Wellman, Samuel T., Otis Iron and Steel Works, Cleveland, Ohio, United States.

1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokio, Japan.

1876. West, Henry Hartley, Naval Architect and Engineer, 14 Castle Street, Liverpool. [*Referee, Liverpool.*]

1874. West, Nicholas James, 36 Upper Park Road, Hampstead, London, N.W.

1877. Western, Charles Robert, Broadway Chambers, Westminster, S.W. [*Donbowes, London.* 3199.]

1877. Western, Maximilian Richard, care of Bombay Burmah Trading Corporation, Bangkok, Siam: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, Lecturer on Engineering, University College, Nottingham.

1867. Weston, Thomas Aldridge, Yale and Towne Manufacturing Co., 62 Reade Street, New York: (or care of J. C. Mewburn, 169 Fleet Street, London, E.C.)

1880. Westwood, Joseph, Napier Yard, Millwall, London, E. [*Westwood, London.* 5065.]

1888. Weyman, James Edwardes, Messrs. Weyman and Johnson, Church Acre Iron Works, Guildford.

1884. Whieldon, John Henry, Campanhia do Beberibe, Rua Imperador, Pernambuco, Brazil: (or care of Ernest W. Whieldon, 42 Worlingham Road, East Dulwich, London, S.E.)

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1887. White, Alfred George, Messrs. Sundheim and Doetsch, Marble Quarries and Works, Huelva, Spain.

1874. White, Henry Watkins, 23 Leadenhall Street, London, E.C.; and 122 Lavender Hill, London, S.W.

1888. White, William Henry, F.R.S., Assistant Controller and Director of Naval Construction, Admiralty, Whitehall, London, S.W.

1885. Whitehead, James George, Mechanical Engineer, Hacienda San Nicolas, Puerto de Supe, Peru.

1890. Whitehouse, Edwin Edward Joseph, Monkbridge Iron Works, Leeds.

1876. Whiteley, William, Messrs. William Whiteley and Sons, Prospect Iron Works, Lockwood, Huddersfield.

1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds. [*Torpedo, Leeds.*]

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1888. Whittle, John, Union Railway Wagon Works, Chorley.

1878. Whytehead, Hugh Edward, North Staffordshire Tramways, Stoke-on-Trent.

1878. Wicks, Henry, Superintendent, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of Dr. Wicks, South View House, West Parade, Newcastle-on-Tyne.)

1863. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1889. Wigham, John Richardson, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin.

1881. Wigzell, Eustace Ernest, Billiter House, Billiter Street, London, E.C. [*Wigzell, London.* 1844.]

1890. Wild, John, Falcon Iron Works, Oldham. [*Falcon, Oldham.*]

1882. Wilder, John, Yield Hall Foundry, Reading.

1886. Wildridge, John, Consulting Engineer and Marine Superintendent, Eastern and Australian Steamship Co., 34 Leadenhall Street, London, E.C.; and care of Messrs. Gibbs Bright and Co., Pitt Street, Sydney, New South Wales.

1890. Wildy, William Lawrence, Leeds Forge, Leeds.

1888. Willans, Peter William, Messrs. Willans and Robinson, Ferry Works, Thames Ditton, Surrey. [*Willans, Thamesditton.*]

1885. Willcox, Francis William, 45 West Sunniside, Sunderland.
1883. Williams, Edward Leader, Engineer, Manchester Ship Canal Co., Manchester. [*Leader, Manchester.* 688.]
1884. Williams, John Begby, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.
1884. Williams, John Rhys, Rhymney Iron Works, Rhymney, R.S.O., Monmouthshire.
1885. Williams, Nicholas Thomas, 6 Great Winchester Street, London, E.C.
1847. Williams, Richard, Brunswick House, Wednesbury.
1890. Williams, Thomas David, 3 Union Buildings, Johannesburg, Transvaal, South Africa; and 13 Akeds Road, Halifax.
1881. Williams, William Freke Maxwell, 29 Great St. Helen's, London, E.C.
1873. Williams, William Lawrence, 16 Victoria Street, Westminster, S.W. [*Snowdon, London.*]
1889. Williams, William Walton, Jun., Messrs. John Lysaght and Co., 36 Gracechurch Street, London, E.C.
1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington.
1870. Willman, Charles, 26 Albert Road, Middlesbrough.
1878. Wilson, Alexander, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1882. Wilson, Alexander Basil, Holywood, Belfast. [*Wilson, Holywood.* 201.]
1872. Wilson, Alfred, The Firs, Norton, near Stourbridge.
1867. Wilson, Henry, 23 Pollard Street, South Shields.
1884. Wilson, James, Chief Engineer of the Daira Sanieh, Egypt; Cairo, Egypt.
1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E.C. [*Wilson, Eastern, London.*]
1863. Wilson, John Charles, 24 Lincoln's Inn Fields, London, W.C. [*Palacol, London.*]
1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.
1890. Wilson, Joseph William, Jun., School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.
1880. Wilson, Robert, 10 St. Bride Street, London, E.C.; and 7 St. Andrew's Place, Regent's Park, London, N.W.
1883. Wilson, Robert, 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.
1890. Wilson, Robert James, Locomotive Works, Ferro Carril Central Norte, Cordoba, Argentine Republic.
1884. Wilson, Thomas, Superintendent, General Steam Navigation Company's Works, Deptford, London, S.E.

1873. Wilson, Thomas Sipling, British Vice-Consul, Brettesnœs, Lofoten Islands, Norway; and Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds: (or care of Messrs. James Bischoff and Sons, 10 St. Helen's Place, London, E.C.)

1888. Wilson, Walter Henry, Messrs. Harland and Wolff, Belfast.

1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1890. Winder, Charles Aston, Messrs. Winder Brothers, Royds Works, Attercliffe, Sheffield.

1886. Windsor, Edwin Wells, 1 Rue du Hameau des Brouettes, Rouen, France.

1890. Wingfield, Digby Charles, Avonmouth Iron Works, Shirehampton, near Bristol.

1887. Winmill, George, Locomotive and Carriage Superintendent, Oudh and Rohilkund Railway, Lucknow, India: (or Hare Street, Romford.)

1872. Winstanley, Robert, Mining Engineer, 28 Deansgate, Manchester.

1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C. [*Lloyd Wise, London.* 2766.]

1871. Withy, Edward, Avon Villa, Parnell, Auckland, New Zealand.

1884. Withy, Henry, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool. [*Withy, West Hartlepool.* 4.]

1878. Wolfe, John Edward, General Manager, Alagoas Railway, Maceio, Brazil: (or care of Rev. Prebendary Wolfe, Arthington, Torquay.)

1878. Wolfenden, Richard, 11 Grafton Street, Moss Side, Manchester.

1878. Wolfenden, Robert, Revenue Cutter "Ling Fêng," care of Commissioner of Customs, Amoy, China: (or 11 Grafton Street, Moss Side, Manchester.)

1888. Wolff, Gustav William, Messrs. Harland and Wolff, Belfast.

1881. Wood, Edward Malcolm, 2 Westminster Chambers, 3 Victoria Street, Westminster, S.W.

1887. Wood, Henry, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1885. Wood, Robert Henry, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds; and 15 Bainbrigge Road, Headingley, Leeds.

1884. Wood, Sidney Prescott, care of H. W. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.

1890. Wood, Thomas Royle, Assistant Locomotive Superintendent, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic

1890. Wood, William, 4 Wolfington Road, West Norwood, London, S.E.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.
1888. Woodford, Ethelbert George, Broad Street Avenue, London, E.C.
1884. Woodward, William, Gas Works, Bromley, Kent.
1887. Worger, Douglas Fitzgerald, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.
1874. Worsdell, Thomas William, Stonycroft, Arnside, Carnforth.
1884. Worssam, Charles Smith, 35 Queen Victoria Street, London, E.C.
1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Massrow, London.* 6656.]
1886. Worthington, Charles Campbell, Messrs. Henry R. Worthington, Hydraulic Works, 145 Broadway, New York, United States: (or care of the Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.)
1888. Worthington, Edgar, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and 243 Upper Brook Street, Manchester.
1860. Worthington, Samuel Barton, Consulting Engineer, 33 Princess Street, Manchester; and Mill Bank, Vicarage Lane, Bowdon, R.O., near Altrincham.
1866. Wren, Henry, Messrs. Henry Wren and Co., London Road Iron Works, Manchester. [*Wrens, Manchester.*]
1881. Wrench, John Mervyn, District Engineer, Indian Midland Railway, Jhansi, N.W. Provinces, India.
1876. Wright, James, Messrs. Ashmore Benson Pease and Co., Stockton-on-Tees. [*Wright, Gasholder, Stockton.* 12.]
1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.
1859. Wright, Joseph, Metropolitan Railway - Carriage and Wagon Co., Saltley Works, Birmingham; and Arundel House, Lower Road, Richmond, Surrey.
1860. Wright, Joseph, 16 Great George Street, Westminster, S.W.; and Lawnswood, Alexandra Road, Upper Norwood, London, S.E.
1878. Wright, William Barton, Rosslyn, Cleveland Road, Ealing, London, W.
1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.
1886. Wylie, James, 79 Sycamore Road, Handsworth, R.O., Birmingham.
1865. Wyllie, Andrew, 1 Leicester Street, Southport.
1883. Wynne-Edwards, Thomas Alured, Agricultural Engineering Works, Denbigh. [*Foundry, Denbigh.*]
1877. Wyvill, Frederic Christopher, 19 East Parade, Leeds.
1889. Yarrow, Alfred Fernandez, Isle of Dogs, Poplar, London, E.
1878. Yates, Henry, Brantford, Ontario, Canada.

1882. Yates, Herbert Rushton, Assistant Engineer, Michigan Air Line Railway Extension, Pontiac, Michigan, United States: (or care of Henry Yates, Brantford, Ontario, Canada.)

1881. Yates, Louis Edmund Hasselts, District Locomotive Superintendent, Eastern Bengal State Railway, Sealdah, Calcutta: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1880. York, Francis Colin, Locomotive Superintendent, Buenos Aires and Pacific Railway, Junin, Buenos Aires, Argentine Republic: (or care of Messrs. Samuel York Sons and Co., Snow Hill, Wolverhampton.)

1889. Young, David, Messrs. Haseltine Lake and Co., 45 Southampton Buildings, London, W.C.

1879. Young, George Scholey, Engineer, Thames Iron Works, Orchard Yard, Blackwall, London, E.

1874. Young, James, Managing Engineer, Lambton Engine and Iron Works, Fence Houses.

1879. Young, James, Low Moor Iron Works, near Bradford.

1887. Young, William Andrew, Messrs. Lobnitz and Co., Renfrew, near Paisley. [*Lobnitz, Renfrew.* 57, *Paisley.*]

1881. Younger, Robert, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1885. Zimmer, George Friedrich, care of J. Harrison Carter, 82 Mark Lane, London, E.C.

ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Cross George Street, Sheffield.

1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland; and The Glen, Newry, Ireland.

1889. Barr, John, Glenfield Engineering Works, East Shaw Street, Kilmarnock.

1886. Bennison, William Clyburn, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1890. Birch, John Grant, 10 and 11 Queen Street Place, London, E.C.

1888. Brown, Harold, 2 Bond Court, Walbrook, London, E.C.

1890. Burt, John Mowlem, Messrs. John Mowlem and Co., 19 Grosvenor Road, Pimlico, London, S.W.

1889. Castle, Frederick George, The People's Palace Technical Schools, Mile End Road, London, E.

1889. Chamberlain, John George, Messrs. Joseph Wright and Co., Neptune Forge, Tipton.

1888. Chrimes, Charles Edward, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1887. Chubb, Edward George, Ironbridge Gas Works, Ironbridge, R.S.O., Shropshire.

1890. Chubb, Richard, Messrs. Gillison and Chadwick, 10 Tower Buildings, Liverpool.

1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E. [*Clowes, London.* 4558.]

1890. Day, Arthur Godfrey, Municipal Technical School, Birmingham.

1883. Fairholme, Capt. Charles, R.N., Heberlein Self-acting Railway Brake Co., 18 St. Dunstan's Hill, London, E.C.

1889. Golby, Frederick William, "Invention" Office, 54 Fleet Street, London, E.C. [*Negotiate, London.* 2669.]

1889. Götz, Carl Johann Wilhelm, Messrs. John M. Sumner and Co., 2 Brazennose Street, Manchester.

1889. Gregory, George Francis, Boarzell, Hawkhurst.

1887. Hind, Enoch, Edgar Rise, Nottingham.

1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham. [*Wagon, Birmingham.*]
1882. Jackson, William, Kingston Cotton Mill, Hull. [*Cotton, Hull.*]
1890. Jennings, Sidney, Stangate, Lambeth, London, S.E.
1884. Livesey, Joseph Montague, Stourton Hall, Horncastle.
1865. Longsdon, Alfred, 9 New Broad Street, London, E.C.
1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield [*Lowood, Sheffield.* 131.]
1883. Macilraith, James, 92 Regent Street, Glasgow. [*Macilraith, Glasgow.*]
1886. Mackenzie, Keith Ronald, Gillotts, Henley-on-Thames.
1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield. [*Matthews, Sheffield.*]
1890. McGillivray, William, Messrs. Levick McGillivray and Co., Albany Steel and File Works, Sheffield.
1889. McKinnel, William, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.
1890. Meggitt, Samuel Newton, Messrs. Ibbotson Brothers and Co., Globe Steel Works, Sheffield.
1889. Miles, William Henry, Town Engineer, Sanitary Board, Johannesburg, Transvaal, South Africa.
1889. Nasmith, Joseph, 4 Arcade Chambers, St. Mary's Gate, Manchester.
1887. Neville, Edward Hermann, Messrs. Julius G. Neville and Co., Oriel Chambers, Liverpool. [*Neville, Liverpool.* 3409.]
1886. Newton, Henry Edward, 6 Bream's Buildings, Chancery Lane, London, E.C.
1888. O'Sullivan, Alfred Timothy, 13 Henrietta Street, Swansea.
1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C. [*Gryphon, London.*]
1886. Peacock, William J. P., Wells Street, Oxford Street, London, W.; and 41 St. James' Street, London, S.W.
1888. Peake, Robert Cecil, Cumberland House, Redbourn, near St. Albans.
1887. Peech, Henry, Phœnix Bessemer Steel Works, near Sheffield.
1887. Peech, William Henry, Phœnix Bessemer Steel Works, near Sheffield.
1890. Perry, Edwin, 25 Side, Newcastle-on-Tyne.
1884. Phillips, Richard Morgan, 21 to 24 State Street, New York, United States. [*Sarita, New York.*]
1886. Raven, Henry Baldwin, Messrs. Hare and Co., Temple Chambers, Temple Avenue, London, E.C.
1882. Ridehalgh, George John Miller, Fell Foot, Newby Bridge, Ulverston.
1888. Rowell, John Henry, New Brewery, High Street, Gateshead.
1883. Sandham, Henry, Keeper, Science and Art Department, South Kensington Museum, London, S.W.

1875. Schofield, Christopher J., Vitriol and Alkali Works, Clayton, near Manchester.

1890. Schofield, John William, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1887. Scott, Walter, Victoria Chambers, Grainger Street West, Newcastle-on-Tyne. [*Contractor, Newcastle-on-Tyne.*]

1878. Stalbridge, The Right Hon. Lord, 12 Upper Brook Street, Grosvenor Square, London, W.

1886. Stumore, Frederick, 34 Leadenhall Street, London, E.C.

1890. Taylor, John, 99 and 101 Fonthill Road, Finsbury Park, London, N.; and Stockport.

1884. Tilfourd, George, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1887. Tozer, Edward Sanderson, Phœnix Bessemer Steel Works, near Sheffield.

1888. Tucker, Thomas, Messrs. Isaac Tucker and Co., Turk's Head Brewery, Gateshead.

1869. Varley, John, Leeds Forge, Leeds.

1878. Watson, Joseph, Patent Office, 25 Southampton Buildings, London, W.C.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

GRADUATES.

1884. Adam, Frank, Sir W. G. Armstrong Mitchell and Co., Elswick, Newcastle-on-Tyne; and 89 Church Street, Stoke Newington, London, N.

1885. Addis, Frederick Henry, Ajmere, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1890. Alderson, Alexander, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1874. Allen, Francis, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1885. Amos, Ewart Charles, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.; and The Sycamores, Beulah Hill, Upper Norwood, London, S.E.

1880. Anderson, Edward William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S.O., Kent; and Roydon Lodge, Erith, S.O., Kent.

1882. Anderson, William, North Eastern Railway, Locomotive Department, Leeds.

1878. Appleby, Charles, Jun., 89 Cannon Street, London, E.C. [*Appleby's, London.* 1731.]

1883. Appleby, Percy Vavasseur, care of H. Vavasseur, Founder's Hall, St. Swithin's Lane, London, E.C.

1887. Ashby, Joseph Harrison, Dowlais New Furnaces, East Moors, Cardiff; and Ascot Heath, Berkshire.

1889. Ashford, John, Messrs. G. E. Belliss and Co., Ledsam Street Works, Birmingham.

1886. Atkey, Albert Reuben, Corporation Water Works, Nottingham.

1890. Aubin, Percy Adrian, 3 Oakden Street, Kennington Road, Lambeth, London, S.E.; and care of F. Le Gresley, 12 Trossachs Road, East Dulwich Grove, London, S.E.

1888. Bailey, Wilfred Daniel, India-rubber Gutta-percha and Telegraph Works, Casilla de Correo 1212, Buenos Aires, Argentine Republic.

1888. Barker, Eric Gordon, Guyse House, Oxton, R.O., near Birkenhead.

1889. Barrow, Arthur Robert Maclean, Locomotive Department, North Western Railway, Sukkur, India: (or care of A. M. Barrow, 13 Upper Maze Hill, St. Leonard's-on-Sea.)

1882. Barstow, Thomas Hulme, Manager, Kaihu Railway, Dargaville, Auckland, New Zealand.

1888. Bell, Alexander Dirom, The Woll, Hawick.

1884. Bell, Robert Arthur, Locomotive Department, South Indian Railway, Negapatam, India: (or care of Mrs. Bell, 30 Brompton Crescent, London, S.W.)

1890. Bell, William Thomas, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1880. Birkett, Herbert, care of Messrs. S. G. Sansinena and Co., Calle Peru 126, Buenos Aires, Argentine Republic: (or 62 Green Street, Grosvenor Square, London, W.)

1884. Bocquet, Harry, care of Arthur E. Shaw, Estacion Central, Buenos Aires, Argentine Republic: (or care of Mrs. Bocquet, 73 Eardley Crescent, London, S.W.)

1888. Boulding, Sidney, Messrs. Green and Boulding, 21 Featherstone Street, London, E.C.

1886. Bourne, Thomas Johnstone, Formosan Railway, care of H.B.M. Consul, Amoy, China: (or care of Mrs. Bourne, Clyde Villa, Southborough, Tunbridge Wells.)

1888. Bradley, Arthur Ashworth, Robinson Gold Mining Co., P.O. Box 787, Johannesburg, Transvaal, South Africa: (or care of Rev. Gilbert Bradley, St. Edmund's Vicarage, Dudley, Worcestershire.)

1887. Bremner, Bruce Laing, 33 London Road, Carlisle: (or Streatham House, Canaan Lane, Edinburgh.)

1878. Brooke, Arthur, General Post Office, Auckland, New Zealand: (or care of Miss Helen Brooke, Sunnymead, The Rise, Sidcup, S.O., Kent.)

1890. Brousson, Robert Percy, Messrs. Woodhouse and Rawson, Cadby Hall Works, Hammersmith, London, W.

1889. Brown, Arthur Selwyn, 43 Portsdown Road, Maida Vale, London, W.; and Sydney, New South Wales.

1880. Buckle, William Harry Ray, 1 Akenside Hill, Newcastle-on-Tyne. [*Noble, Newcastle.* 663.]

1886. Budenberg, Christian Frederick, 25 Demesne Road, Whalley Range, Manchester.

1890. Burne, Edward Lancaster, Wilmington, Crystal Palace Park Road, Sydenham, London, S.E.

1879. Burnet, Lindsay, Moore Park Boiler Works, Govan, near Glasgow. [*Burnet, Glasgow.* 1513.]

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1886. Cairnes, Frederick Evelyn, care of R. Price-Williams, 4 Victoria Mansions, 32 Victoria Street, Westminster, S.W.

1889. Calastremé, John Carlos, City and Guilds of London Central Institution, Exhibition Road, London, S.W.

1889. Challen, Walter Bernard, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.

1890. Chatwood, Arthur Brunel, Lancashire Safe and Lock Works, Bolton.

1890. Cleeves, John Frederick, Richards Furnace Co., 7 Great St. Helen's, London, E.C.

1885. Clift, Leslie Everitt, Fernbank, Pittville, Cheltenham.

1883. Clinkskill, Alfred Alphonse Rouff, Messrs. James Clinkskill and Son, 1 Holland Place, St. Vincent Street, Glasgow.

1886. Conyers, Sidney Ward, Railway Construction Branch, Public Works Department, Sydney, New South Wales.

1889. Cook, George Norcliffe, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1883. Cotton, Henry Streatfeild, 10 Sussex Square, Hyde Park, London, W.

1888. Cox, Herbert Henry, care of J. McLean, 20 Kelvinhaugh Street, Glasgow.

1887. Crosland, Delevante William, 22 Royal Crescent, Kensington, London, W.

1890. Davidson, Albert, Messrs. Hattersley and Davidson, Arundel Engineering Works, 14 and 16 Arundel Street, Sheffield.

1884. Dixon, John, Westley Street, Lytham, near Preston, Lancashire.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham. [*Vulcan, Birmingham.*]

1885. Edwards, Walter Cleeve, Assistant Engineer, Midland Railway, Greymouth, New Zealand.

1887. England, William Henry, 40 Matlock Terrace, Leeds.

1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square, London, W.

1890. Garrett, Frank, Jun., Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk.

1886. Grant, Percy, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic.

1887. Hanby, Wrey Albert Edward, Assistant Engineer, Public Works Department, Bengal, India: (or care of E. T. Hanby, 34 Bassein Park Road, Shepherd's Bush, London, W.)

1889. Harrison, Gilbert Harwood, Lieutenant R.E., Assistant Inspector of Gun Carriages, Royal Arsenal, Woolwich.

1890. Hatton, Thomas Reginald, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1889. Hayward, Robert Francis, Messrs. Crompton and Co., Arc Works, Chelmsford.

1885. Head, Archibald Potter, Queen's Square, Middlesbrough.

1890. Heap, Ray Douglas Theodore, Messrs. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.; and 35 Addison Gardens, Kensington, London. W.

1882. Heath, Ashton Marler, care of Sir A. M. Rendel, 8 Great George Street, Westminster, S.W.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham. [*Heagard, Birmingham.*]

1874. Hedley, Thomas, 1 Huntly Road, Fairfield, Liverpool.

1883. Hill, John Kershaw, Engineer and Manager, West Surrey Water Works, High Street, Walton-on-Thames.

1887. Hogg, William, Cosmos Club, Buenos Aires, Argentine Republic; (or Craigmore, Blackrock, near Dublin.)

1867. Holland, George, Mechanical Department, Grand Trunk Railway, Montreal, Canada.

1884. Holt, Follett, Ferro Carril Buenos Aires y Rosario, Campana, Argentine Republic: (or care of Robert Hallett Holt, 3 Devonshire Terrace, Portland Place, London, W.)

1889. Hosgood, Thomas Watkin, Richardson Street, Swansea.

1889. Hosken, Arthur Fayrer, Great Eastern Railway, Stratford Works, London, E.

1889. Howard, Geoffrey, Britannia Iron Works, Bedford.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1890. Jones, Arthur Dansey, Locomotive Works, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1889. Joy, Basil Humbert, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1883. Lander, Philip Vincent, Messrs. Lander and Mulford, Estacion Central, Buenos Aires, Argentine Republic: (or Lyndhurst, Hampton Wick, R.O., Kingston-on-Thames.)

1881. Lawson, James Ibbs, Resident Engineer, New Zealand Railways, Invercargill, Otago, New Zealand.

1886. Lewis, William Thomas, Jun., Engineer's Office, Bute Docks, Cardiff; and Llwyn-yr-eos, Abercanaid, near Merthyr Tydfil.

1881. Macdonald, Ranald Mackintosh, Messrs. Booth Macdonald and Co., Carlyle Engineering and Implement Works, Christchurch, New Zealand; and P.O. Box 89, Christchurch, New Zealand.

1883. Mackenzie, Thomas Brown, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow; and 342 Duke Street, Glasgow.

1883. Malan, Ernest de Mérindol, Howden.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1889. Marshall, Frank Theodore, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1888. Marten, Hubert Bindon, Contractor's Office, Great Western Railway, Pangbourne, near Reading; and Pedmore, Stourbridge.

1886. Mattos, Alvaro Gomes de, 98 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1887. May, Harold Milton, Hunslet Engine Works, Leeds.

1867. Mitchell, John, Swaithe Hall, Barnsley.

1868. Moor, William, Cross Lanes, Hetton-le-Hole, near Fence Houses.

1878. Newall, John Walker, Messrs. John W. Newall and Co., Atlantic Works, City Road, Manchester. [*Lawen, Manchester.*]

1882. Noble, Saxton William Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1883. O'Connor, John Frederick, 16 and 18 Exchange Place, New York, United States.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1881. Oswell, William St. John, 110 Cannon Street, London, E.C.

1889. Paget, Edgar Lyon, Messrs. A. Paget and Co., Loughborough.

1883. Palchoudhuri, Bipradas, Moheshgunj Factory, Krishnugher, Bengal.

1887. Paterson, John Edward, Locomotive Engineer's Office, New South Wales Government Railways, Wilson Street, Eveleigh, Sydney, New South Wales.

1890. Philipson, John, Jun., Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne.

1884. Philipson, William, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1890. Powell, Frederick, York House, Malvern Link, Malvern.

1887. Price-Williams, John Morgan, Engineer's Office, Great Northern Railway, 7 York Road, King's Cross, London, N.

1887. Pullen, William Wade Fitzherbert, 70 Beauchamp Street, Riverside, Cardiff.

1884. Reynolds, Thomas Blair, 5 Great George Street, Westminster, S.W.

1885. Ripley, Philip Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1887. Rogers, Horace Wyon, 43 Upper Thames Street, London, E.C.

1881. Rogers, Philip Powys, Assistant Engineer, Wardha Coal State Railway, Warora, Central Provinces, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1889. Roope, Walter, care of E. G. Grinlinton, Portswood, Nuwara Eliya, Ceylon: (or care of Mrs. Roope, 27 Stafford Terrace, Kensington, London, W.)

1884. Roux, Paul Louis, 54 Boulevard du Temple, Paris.

1888. Rümmele, Alfredo, 17 Via Principe Umberto, Milan, Italy.

1882. Sanchez, Juan Emilio, Talleres de Marina Nacionales, Tigre, Buenos Aires, Argentine Republic: (or care of Messrs. J. E. and M. Clark and Co., 9 New Broad Street, London, E.C.)

1890. Sanders, Percy Henry, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.

1890. Saxelby, Herbert Raffaelle, Messrs. J. Copeland and Co., Poultney Street Engine Works, Dobbies Loan, Glasgow.

1881. Scott, Ernest, Close Works, Newcastle-on-Tyne. [*Esco, Newcastle-on-Tyne.* 432.]

1886. Silcock, Charles Whitbread, Engine Department, Medina Dock, West Cowes.

1887. Simkins, Charles Wickens, Jun., Amguri Tea Estate, Amguri Post Office, Sibsagar, Assam, India: (or care of Charles W. Simkins, The Lodge, Lowdham, near Nottingham.)

1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1889. Smith, Henry Buckley Bingham, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow.

1890. Smith, Thomas Ridsdill, Earle's Shipbuilding and Engineering Works, Hull.

1883. Swale, Gerald, Stow Cottage, Paisley.

1887. Tabor, Edward Henry, 44 Lansdowne Road, Notting Hill, London, W.

1889. Tangye, Harold Lincoln, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1885. Tangye, John Henry, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1884. Taylor, Joseph, 19 Foskett Road, Fulham, London, S.W.

1884. Taylor, Maurice, 4 Rue la Boëtie, Paris.

1884. Templeton, Edwin Arthur Slade, 42 Boscombe Road, Shepherd's Bush, London, W.

1889. Treharne, Gwilym Alexander, Pontypridd; and Aberdare.

1878. Waddington, John, Jun., 35 King William Street, London Bridge, London, E.C.

1888. Waddington, Samuel Sugden, Wortley Villa, Sydenham, London, S.E.

1885. Wakefield, William Marsden, care of Mark W. Carr, Government Railway, Pietermaritzburg, Natal, South Africa.

1884. Walker, Ralph Teasdale, Fabrick Olean, Sitoebondo, Java: (or Kaliemaas, Alleyne Park, West Dulwich, London, S.E.)

1888. Waring, Henry, Engineer, Dublin Laundry Co., Milltown, near Dublin; and 109 Moyne Road, Dublin.

1886. Warren, Frank Llewellyn, 73 Breakspears Road, St. John's, London, S.E.

1886. Wesley, Joseph A., Clarke's Crank and Forge Works, Lincoln.

1883. Westmacott, Henry Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Weymouth, Francis Marten, 33 Alfred Road, Acton, London, W.

1888. Whichello, Richard, Messrs. Max Nothmann and Co., Rio de Janeiro, Brazil: (or 44 Trumpington Street, Cambridge.)

1889. Wigham, John Cuthbert, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin.

1889. Willis, Edward Turnley, 99 Shooter's Hill Road, Blackheath, London, S.E.

1890. Wilson, Alexander Cowan, Farnley Iron Works, near Leeds.

1889. Winkfield, Richard Ernest, Locomotive Department, Great Western Railway, Swindon.

1890. Winmill, Hallett, Engineer, Pigg's Peak Gold Mining Co., Swaziland, South Africa; care of Messrs. W. R. Brown and Co., Barberton, Transvaal, South Africa: (or care of C. C. Winmill, 14 Hamfrith Road, Stratford, London, E.)

1887. Wrench, John Henry Kirke, Park Lodge, Baslow, Chesterfield.

1889. Wright, Howard Theophilus, 16 Great George Street, Westminster, S.W.

1890. Wright, William Carthew, General Post Office, Melbourne, Victoria: (or care of Dr. Gaskoin Wright, 253 Eccles New Road, Salford, Manchester.)

1888. Yates, Edward, 50 St. John's Hill Grove, New Wandsworth, London, S.W.

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

August 1878.

1st. The name of the Association is "The Institution of Mechanical Engineers."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(a.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(b.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(c.) To acquire and dispose of property for the purposes aforesaid.

(d.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

August 1878.

INTRODUCTION.

Whereas an Association (hereinafter called "the existing Institution") called "The Institution of Mechanical Engineers" has long existed for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply, and the existing Institution consists of Members, Graduates, Associates, and Honorary Life Members, and is possessed of books, drawings, and property used for the objects aforesaid;

And whereas the Institution is formed for furthering and extending the objects of the existing Institution, by a registered Association, under the Companies Acts 1862 and 1867; and terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

Now therefore it is hereby agreed as follows:—

CONSTITUTION.

1. For the purpose of registration the number of Members of the Institution is unlimited.

MEMBERS.

2. The subscribers of the Memorandum of Association, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who, being a Member of the existing Institution, shall agree to transfer his membership of the existing Institution, and all rights and obligations incidental thereto, to the Institution, and to be registered as a Member of the Institution accordingly.

4. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

5. The rights and privileges of every Member of the Institution shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

QUALIFICATION AND ELECTION OF MEMBERS.

6. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

7. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

8. Any person may become a Graduate, Associate, or Honorary Life Member of the Institution, who, being already a Graduate, Associate, or Honorary Life Member of the existing Institution, shall agree to transfer his interest in the existing Institution, and all rights and obligations incidental thereto, to the Institution.

9. The Institution may admit such other persons as may be hereafter qualified and elected in that behalf as Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: Provided that no Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

10. The qualification and mode of election of Graduates, Associates, and Honorary Life Members, shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

ENTRANCE FEES AND SUBSCRIPTIONS.

11. The Entrance Fees and Subscriptions of Members, Graduates, and Associates, shall be prescribed by the By-laws from time to time in force, as provided by the Articles: Provided that no Entrance Fee shall be payable by a Member, Graduate, or Associate of the existing Institution.

EXPULSION.

12. If any Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the list of Members, Graduates, or Associates, as the case may be, by the Council, at any time afterwards, and he shall thereupon cease to

have any rights as a Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: Provided always, that this regulation shall not be construed to compel the Council to remove any name if they shall be satisfied the same ought to be retained.

13. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the list of Members, Graduates, or Associates (as the case may be), and such person shall thereupon cease to be a Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

14. The first General Meeting shall be held on such day, within four months of the registration of the Institution, as the Council shall determine. Subsequent General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

15. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

16. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members of the Institution, specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members

of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

17. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every Member of the Institution, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

18. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

19. Twenty Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members shall constitute a quorum for the purposes of a Special Meeting.

20. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

21. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if

no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

22. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded, and by a poll when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman, and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: Provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

23. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: Provided that the Chairman may review his decision at the same Meeting if any error be then pointed out to him.

BY-LAWS.

24. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be added or substituted as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members at an Annual General Meeting, after notice of the proposed alteration or addition announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

25. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-

Presidents; and the first Council (which shall include Past-Presidents of the existing Institution) shall be as follows:—

PRESIDENT.

John Robinson	Manchester.

PAST-PRESIDENTS.

Sir William G. Armstrong, C.B., D.C.L., LL.D., F.R.S.	Newcastle-on-Tyne.
Frederick J. Bramwell, F.R.S.	London.
Thomas Hawksley	London.
James Kennedy	Liverpool.
John Penn, F.R.S.	London.
John Ramsbottom	Manchester.
C. William Siemens, D.C.L., F.R.S.	London.
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S.	Manchester.

VICE-PRESIDENTS.

I. Lowthian Bell, M.P., F.R.S.	Northallerton.
Charles Cochrane	Stourbridge.
Edward A. Cowper	London.
Charles P. Stewart	London.
Francis W. Webb	Crewe.
Percy G. B. Westmacott	Newcastle-on-Tyne

COUNCIL.

Daniel Adamson	Manchester.
John Anderson, LL.D., F.R.S.E.	London.
Henry Bessemer	London.
Henry Chapman	London.
Edward Easton	London.
David Greig	Leeds.
Jeremiah Head	Middlesbrough.
Thomas R. Hetherington	Manchester.
Henry H. Laird	Birkenhead.
William Menelaus	Dowlais.
Arthur Paget	Loughborough.
John Penn, Jun.	London.
George B. Rennie	London.
William Richardson	Oldham.
John C. Wilson	Bristol.

26. The first Council shall continue in office till the Annual General Meeting in the year 1879. The President, two Vice-Presidents, and five Members of the Council (other than Past-Presidents), shall retire at each succeeding Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree amongst themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

27. The election of a President, Vice-Presidents, and Members of the Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

28. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another, and the President or Members of the Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

29. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws the officers and servants of the Institution shall be appointed and removed by the Council.

30. The powers and duties of the officers of the Institution shall (subject to any express provision in the By-laws) be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

31. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three Members of Council shall form a quorum.

32. The Council shall acquire the property of the existing Institution, and shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

33. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A.) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B.) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C.) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D.) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E.) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F.) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

34. The Council may, with the authority of a resolution of the Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution.

35. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members of the Institution in General Meeting, shall be afterwards impeached by any Member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

36. A notice may be served by the Council of the Institution upon any Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to such Member, Graduate, Associate, or Honorary Life Member, at his registered place of abode.

37. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post, and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

38. No Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom shall be entitled to any notice; and all proceedings may be had and taken without notice to such Member in the same manner as if he had had due notice.

By-laws.

(*Last Revision, January* 1890.)

MEMBERSHIP.

1. Members, Graduates, Associates, and Honorary Life Members of the existing Institution, may, upon signing and forwarding to the Secretary of the Institution a claim according to Form D in the Appendix, become Members, Graduates, Associates, or Honorary Life Members respectively of the Institution without election or payment of entrance fees.

2. Candidates for admission as Members must be Engineers not under twenty-four years of age, who may be considered by the Council to be qualified for election.

3. Candidates for admission as Graduates must be Engineers holding subordinate situations and not under eighteen years of age; and they may afterwards be admitted as Members at the discretion of the Council.

4. Candidates for admission as Associates must be gentlemen not under twenty-four years of age, who from their scientific attainments or position in society may be considered eligible by the Council.

5. The Council shall have the power to nominate as Honorary Life Members gentlemen of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings, but Members only shall be entitled to vote thereat.

7. The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following: — for Members, M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

8. Subject to such regulations as the Council may from time to time prescribe, any Member, Graduate, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. An Entrance Fee of £2 shall be paid by each Member, except Members of the existing Institution, who shall pay no Entrance Fee, and Graduates admitted as Members, who shall pay an Entrance Fee of £1. Each Member shall pay an Annual Subscription of £3.

10. An Entrance Fee of £1 shall be paid by each Graduate, except Graduates of the existing Institution, who shall pay no Entrance Fee. Each Graduate shall pay an Annual Subscription of £2.

11. An Entrance Fee of £2 shall be paid by each Associate, except Associates of the existing Institution, who shall pay no Entrance Fee. Each Associate shall pay an Annual Subscription of £3.

12. All Subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first Subscription of Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

13. In the case of Members, Associates, or Graduates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

14. Any Member or Associate whose subscription is not in arrear may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds. All compositions shall be deemed to be capital moneys of the Institution.

15. The Council may at their discretion reduce or remit the Annual Subscription, or the arrears of Annual Subscription, of any Member who shall have been a subscribing Member of the Institution for twenty years, and shall have become unable to continue the Annual Subscription provided by these By-laws.

16. No Proceedings or Ballot Lists shall be sent to Members, Associates, or Graduates, who are in arrear with their subscriptions more than twelve months, and whose subscriptions shall not have been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, GRADUATES, AND ASSOCIATES.

17. A recommendation for admission according to Form A in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members if the application be for admission as a Member or Associate, and by three Members if it be for a Graduate.

18. All Elections shall take place by ballot, three-fifths of the votes given being necessary for election.

19. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

20. The Elections shall take place at the General Meetings only.

21. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form B; but his name shall not be added to the list of Members, Graduates, or Associates of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form C in the Appendix.

22. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

23. A Graduate or Associate desirous of being transferred to the class of Members shall forward to the Secretary a recommendation according to Form E in the Appendix, signed by not less than five Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form F if an Associate, and according to Form G if a Graduate; but his name shall not be added to the list of Members until he shall have signed the Form H, and, if a Graduate, shall have paid £1 additional entrance fee, and £1 additional subscription for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

24. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

25. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands

of the Secretary for current expenses. He shall be appointed by the Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

26. The Secretary of the Institution shall be appointed as and when a vacancy occurs by the Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

27. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

28. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council.

29. All books, drawings, communications, &c., shall be accessible to the Members of the Institution at all reasonable times.

30. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

31. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

32. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

33. The General Meetings shall be conducted as far as practicable in the following order :—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or, with the consent of the Council, by the Author.

34. Each Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member asks that this shall be done.

35. Every Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

36. The President shall ex officio be Member of all Committees of Council.

37. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

38. The Council shall present the yearly accounts to the Members at the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members.

39. Any Member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

40. At any Meeting of the Institution any Member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being not under twenty-four years of age, and desirous of admission into the Institution of Mechanical Engineers, we the undersigned proposer and seconder from our personal knowledge, and we the three other signers from trustworthy information, propose and recommend him as a proper person to become a thereof.

Witness our hands, this day of

Members.

FORM B.

Sir,—I have to inform you that on the you were elected a of the Institution of Mechanical Engineers. In conformity with the rules, your election cannot be confirmed until the enclosed form be returned to me with your signature, and until your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM C.

I, the undersigned, being elected a of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM D.

As a of the Institution of Mechanical Engineers, I claim to become a of the Association incorporated under the same name.

Please register me as a

FORM E.

Mr. being of the required age, and desirous of being transferred into the class of Members of the Institution, we, the undersigned, from our personal knowledge, recommend him as a proper person to become a Member of the Institution of Mechanical Engineers.

FORM F.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature. If this be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature, and until your additional Entrance Fee (£1) and additional Annual Subscription (£1) be paid for the current year. If these be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of Members of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

Institution of Mechanical Engineers.

PROCEEDINGS.

JANUARY 1890.

The FORTY-THIRD ANNUAL GENERAL MEETING of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, 29th January 1890, at Half-past Seven o'clock p.m.; WILLIAM ANDERSON, Esq., D.C.L., Vice-President, in the chair, succeeded by JOSEPH TOMLINSON, Esq., President elected at the Meeting.

The Minutes of the previous Meeting were read, approved, and signed by the Chairman.

The CHAIRMAN announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following thirty-two candidates were found to be duly elected:—

MEMBERS.

CHARLES STUART BAILEY, . . .	London.
JOHN ALEXANDER BRODIE, . . .	Liverpool.
ROBERT JAMES CROSS, . . .	Bristol.
WILLIAM ERNEST DALBY, . . .	Crewe.
RICHARD MOUNTFORD DEELEY, . .	Derby.
TOM DREWET, ...	Bombay.
WILLIAM ROBERT HARRISON, . . .	Hull.
EDWARD GEORGE HILLER, . . .	Manchester.
BENJAMIN HOOKER, ...	London.
FREDERICK HOWARD LIVENS, . .	Lincoln.
RICHARD THOMPSON MACAN, . .	London.
STEPHEN MASSEY, ...	Manchester.

ROBERT DOUGLAS MUNRO,	Glasgow.
WILLIAM HENRY POTTER,	Nottingham.
JOHN PRICE,	Workington.
FRANK REEVES,	Buenos Aires.
GLENFORD MITCHELL RICHES,	Grimsby.
GEORGE ANDREW SCHOFIELD,	Alexandria.
JACOB SULZER,	Winterthur.
GEORGE HENRY WALKEDEN,	Birmingham.
WILLIAM GEORGE WALKER,	Bristol.
GEORGE COGHLAN WATSON,	London.
THOMAS DAVID WILLIAMS,	Johannesburg.
WILLIAM WOOD,	London.

ASSOCIATES.

JOHN MOWLEM BURT,	London.
ARTHUR GODFREY DAY,	Birmingham.

GRADUATES.

PERCY ADRIAN AUBIN,	London.
WILLIAM THOMAS BELL,	Lincoln.
RAY DOUGLAS THEODORE HEAP,	London.
ARTHUR DANSEY JONES,	Bolton.
THOMAS RIDSDILL SMITH,	Hull.
WILLIAM CARTHEW WRIGHT,	Melbourne.

The following Annual Report of the Council was then read :—

ANNUAL REPORT OF THE COUNCIL.

1890.

In presenting the Members with their Annual Report on the position of the Institution and the progress made during the past year, the Council will commence with the usual statistics of membership and financial condition.

At the end of last year the number of names of all classes on the roll of the Institution was 1858, as compared with 1806 at the end of the previous year, showing a net gain of 52. During 1889 there were added to the register 123 names; against which the loss by deceases was 25, and by resignation or removal 46.

The following Transferences of Graduates to the class of Members have been made by the Council in 1889:—

Andrew Brown,	Kurrachee.
Frederick Alexander William Brown,	Woolwich.
Leslie Clarke,	London.
George Bellamy Clifton,	London.
Joseph Davis,	Manchester.
James Harold Howard,	Bedford.
Francis Watkins Keen,	Westbromwich.
Seymour William Price-Williams,	London.
George Herbert Wailes,	Watford.

The following thirty-one Deceases of Members of the Institution have occurred during the past year:—

Charles Fanshawe Atkinson,	Sheffield.
Thomas Arthur Bewley,	Dublin.
William Sutton Bocquet,	Lahore.
Thomas Chatwin,	Birmingham.
Benjamin Colley,	Westbromwich.
James Davidson,	Plumstead.
William Frederick Dennis,	London.
Edward Fletcher,	Newcastle-on-Tyne.
Arthur Robert William Fulton,	Wellington, N.Z.
Ebenezer Edwin Gilbert,	Montreal.

EDWIN JAMES GRICE,	Reigate.
ALFRED C. HILL,	South Bank.
THOMAS HINDMARSH,	London.
WILLIAM LYSTER HOLT,	London.
JAMES HOWARD,	Bedford.
EDWARD A. JEFFREYS,	Leeds.
JOHN MCCONNOCHIE,	Cardiff.
JOHN MUSGRAVE,	Bolton.
WALTER MONTGOMERIE NEILSON,	Glasgow.
ROBERT STIRLING NEWALL, F.R.S.,	Gateshead.
RICHARD PEACOCK, M.P.,	Manchester.
ROBERT WEBB PEARCE,	Howrah.
CHARLES REBOUL SACRÉ,	Manchester.
JAMES SIMPSON,	London.
GEORGE SPENCER,	London.
ROBERT PAULSON SPICE,	London.
GEORGE WILSON STEVENSON,	London.
WILLIAM STROUDLEY,	Brighton.
Captain HARRY BORLASE WILLOCK, R.E.,	London.
EDWARD WALTER NEALOR WOOD (Graduate),	Huelva.
SAKU YOKOI (Graduate),	Paris.

Of these Mr. Fletcher and Mr. Peacock were both of them original Members of the Institution from its establishment in 1847, and the latter was for many years a Member of Council and a Vice-President. Mr. Neilson also was for several years a Member of Council.

The following twenty-three gentlemen have ceased to be Members of the Institution during the past year :—

AUGUSTUS JESSE BOWIE, JUN.,	San Francisco.
JAMES FLETCHER BURGESS,	London.
The Hon. HERBERT JOHN CAIRNS (Graduate),	Newcastle-on-Tyne.
RAPHAEL MARTINEZ CAMPOS,	Buenos Aires.
CHARLES CARVER (Graduate),	Nottingham.
FREDERICK MCDAKIN CLENCH (Graduate),	Ceylon.
ROBERT COLES,	Birmingham.
ROBERT HENRY ELLACOTT,	Plymouth.
JOSEPH FITTON,	Manchester.
ALFRED GREIG (Graduate),	London.
WILLIAM STIRLING HALSEY, JUN. (Graduate),	Amritsar.
RICHARD HEATHFIELD,	Darlaston.
AUGUSTE LÉON,	Paris.

John Needham Longden,	London.
Richard St. George Moore,	London.
William Weallens Shanks,	Howrah.
Frederick Seaton Snowdon,	London.
John Classon Stephens,	Dublin.
James Taylor,	Birkenhead.
Robert Thompson,	Wigan.
Eric Hugo Waldenström,	Stockholm.
John Waugh,	Bradford.
Henri Michel Wolff,	Llanrwst.

In addition to these there have been twenty-three Resignations of membership.

The Accounts for the year ending 31 December 1889 are now submitted to the Members (*see* pages 12–15), after having been passed by the Finance Committee, and certified by Mr. Robert A. McLean, chartered accountant, the auditor appointed by the Members at the last Annual General Meeting. The receipts during the year were £6,260 18*s.* 3*d.*, while the expenditure, actual and estimated, was £4,849 12*s.* 8*d.*, leaving a balance of receipts over expenditure of £1,411 5*s.* 7*d.* The financial position of the Institution at the end of the year is shown by the balance sheet: the total investments and other assets amount to £31,757 7*s.* 3*d.*; and allowing £600 for accounts owing but not yet rendered, the capital of the Institution amounts to £31,157 7*s.* 3*d.*, of which the greater part, as seen from the balance sheet, is invested in Railway Debenture Stocks, registered in the name of the Institution. The certificates of the whole of the securities have been duly audited by the Finance Committee and the auditor.

Since the reading and discussion of the first Report of the Research Committee appointed to draw up a standard system of Marine-Engine Trials, which was placed before the Members at the Spring Meeting, further trials have been made under the direction of the chairman, Professor Kennedy, and by the obliging permission of the ship-owners concerned. A further report on three of these trials, including a high-speed steamer for express passenger traffic

and two cargo vessels of very different kinds, is in course of preparation; and as soon as ready will be presented to the Members for consideration and discussion.

The Research Committee on the value of the Steam Jacket, under the chairmanship of Mr. Henry Davey, have presented their first Report, comprising the records of a large number of complete sets of previous experiments, collated and arranged by the chairman and Mr. Donkin; and the Council have directed the publication of these records in the Institution Proceedings. Meanwhile trials are being made, and others are in prospect, under such conditions as it is hoped will lead to further results of practical value for engineers.

For the purpose of the intended experiments on the friction of pivot bearings, the necessary machinery has been made under the direction of the Research Committee on Friction, of which Mr. Tomlinson is the chairman. Various circumstances have delayed the actual carrying out of the experiments, which however it is hoped there will soon be an opportunity of commencing.

On the recommendation of Dr. Anderson, arising out of Professor Roberts-Austen's investigations into the application of the periodic law to the mechanical properties of materials, the Council have recently decided upon starting a Research Committee with the object of investigating the effects of small admixtures of certain elements on the mechanical and physical properties of Iron, Copper, and Lead. This Committee, of which Dr. Anderson has been appointed chairman, is to be called the "Alloys Research Committee." They are led to believe that, by dealing in the first instance with these three distinct metals simultaneously, the investigations into their properties when alloyed with minute doses of foreign ingredients may mutually throw light upon one another, and thereby facilitate the progress of the research, and the attainment of results having a practical bearing upon the work of mechanical engineers. On a former occasion the Council received from Mr. John A. F. Aspinall the valuable suggestion of the desirability of enquiring into the serious deterioration experienced during recent years in the

durability of the copper fire-boxes and brass tubes of locomotive boilers; and it seems not unreasonable to hope that one result of the investigations now about to be entered upon may be to elucidate the true causes of this deterioration, and to indicate the means of restoring to copper the identical properties which enabled locomotive fire-boxes of this material to accomplish formerly so much longer a mileage than it has latterly been found possible to get out of them. The laws regulating the effects of small admixtures of other elements with iron will also it is hoped be arrived at. These are some of the instances of many similar benefits which may be looked for from the work of the newly started Research Committee.

The donations presented to the Library of the Institution during the past year are enumerated in pages 16–25; for all of these the Council are glad to record their thanks to the several Donors. Members able to present original pamphlets and records of experimental research, and other works valuable for reference, are requested to bear in mind how welcome are such contributions for permanent preservation in the Library.

The General Meetings in 1889 were the Annual General Meeting and the Spring Meeting, both held in London; the Summer Meeting in Paris; and the Autumn Meeting in London. Altogether eleven sittings were occupied in the reading and discussion of the following Papers, which are published in the Proceedings:—

On the use of Petroleum Refuse as Fuel in Locomotive Engines; by Mr. Thomas Urquhart. Supplementary Paper.

On Compound Locomotives; by Mr. R. Herbert Lapage.

On the latest development of Roller Flour Milling; by Mr. Henry Simon.

Address by the President.

Research Committee on Marine-Engine Trials: Report upon Trials of the S.S. "Meteor"; by Professor Alexander B. W. Kennedy, F.R.S., Honorary Life Member, Chairman.

Description of an Apparatus for Drying in Vacuum; by Mr. Emil Passburg. Communicated through Mr. Samuel Geoghegan.

Description of the Lifts in the Eiffel Tower; by Mr. A. Ansaloni. Supplemented by Results of Working to date, communicated verbally by Mr. Gustave Eiffel, President of the Société des Ingénieurs Civils.

The Rationalization of Regnault's Experiments on Steam; by Mr. J. Macfarlane Gray.

On Warp Weaving and Knitting, without Weft; by Mr. Arthur Paget, Vice-President.

On Gas Engines, with description of the Simplex Engine; by Mr. Édouard Delamare-Deboutteville.

On the results of Blast-Furnace Practice with Lime instead of Limestone as Flux; by the President.

Description of a Rotary Machine for making Block-bottomed Paper Bags; by Mr. Job Duerden, communicated through Mr. Henry Chapman.

Further Experiments on Condensation and Re-evaporation of Steam in a Jacketed Cylinder; by Major Thomas English, R.E.

The attendances during 1889 were as follows:—at the Annual General Meeting 80 Members and 82 Visitors; at the Spring Meeting 82 Members and 46 Visitors; at the Summer Meeting 189 Members and 79 Visitors; and at the Autumn Meeting 67 Members and 39 Visitors.

The Summer Meeting of the Institution was for the third time held in Paris on the occasion of the International Exhibition, as had been the case at each of the two previous Exhibitions held there in 1867 and 1878. Again, as formerly, the morning meetings for the reading and discussion of papers took place in the large lecture theatre of the Conservatoire des Arts et Métiers, on the invitation of the Director, Colonel Laussedat. From the Société des Ingénieurs Civils de France a warm welcome was received through their President, M. Eiffel; to whom, and to the Reception Committee of the Society, the Members of the Institution are indebted for the cordial reception and invitations so handsomely proffered to them during the Meeting, and for the arrangements whereby they were enabled to visit so many engineering and manufacturing works of interest both in Paris and elsewhere. On the occasion of the visit to the new Calais Harbour Works by the Members returning from the Paris Meeting, the President was presented by M. Fournier, the President of the Calais Chamber of Commerce, with a handsome bronze Medal, which had been struck in commemoration of the opening of the new Harbour Works in the previous month by the

President of the French Republic. The Medal will be preserved in the Institution, as a welcome memento of the visit.

As a sequel to a Meeting which was so greatly enjoyed by the Members who were fortunate enough to be able to attend it, the Council have already had the gratification of announcing to the Members that they have nominated as an Honorary Life Member of the Institution M. Gustave Eiffel, President of the Société des Ingénieurs Civils, in acknowledgment of all that was so kindly done by the Society under his auspices for ensuring the success of the Paris Meeting, and also in recognition of his eminent position in the engineering profession, and of the world-wide celebrity attaching to his works. The Council have also on behalf of the Institution presented to Mr. Henry Chapman a Recording Barometer, bearing a suitable inscription, in testimony of their grateful appreciation of his renewed kindness in again giving his valued aid and experience as Honorary Secretary for this third successful Summer Meeting in Paris, after he had obligingly acted in the same capacity for the two previous Paris Meetings. The cordial thanks of the Institution, engrossed upon vellum and framed, have been presented by the Council to M. Henri Vaslin, in recognition of the energetic and obliging manner in which he shared in maturing and carrying out the various arrangements; and to M. Armand de Dax, the Agent General of the Société des Ingénieurs Civils, the Council have presented on behalf of the Institution a Kodak Camera, as a memento of his obliging exertions for the advantage of the Members attending the Meeting.

While the Meeting in Paris was being so fully enjoyed by all concerned, there occurred a terrible colliery explosion at St. Étienne (Loire), France, which resulted in the deaths of over two hundred colliers. In response to an appeal at once addressed by the President to the Members who had attended the Meeting, a sum of £67 10*s.* 0*d.* in aid of the sufferers was promptly received from sixty-six contributors, and was forwarded through the Société des Ingénieurs Civils, by whose President, M. Eiffel, a cordial acknowledgment was returned for this welcome and appropriate token of sympathy.

The Summer Meeting of the Institution in the present year is intended to be held in Sheffield, an interval of twenty-nine years having elapsed since the previous Meeting held there in 1861. Cordial offers of assistance for the realisation of this intention have already been received from the Mayor, the Master Cutler, and various local Members and friends of the Institution.

It will be remembered that, in his presidential remarks two years ago at the Annual General Meeting of the Institution, Mr. Carbutt urged the great practical importance of the recommendation made by Lord Morley's ordnance committee, of which he had himself been a member, that in connection with the government ordnance factories there should be a chief mechanical engineer holding a civilian appointment, who should be in charge of and responsible for manufacture in all its branches. To this recommendation the Council are glad to recognise that the fullest effect has recently been given by the appointment of their colleague, Dr. William Anderson, Vice-President, as Director General of Ordnance Factories; and while cordially congratulating him upon being called upon to fulfil the duties of so responsible a position, they are sure their opinion will be shared by the Members of this Institution, that mechanical engineers in general, as well as the country at large, may be still more heartily congratulated upon the appointment of a trained and experienced mechanical engineer to a post that pre-eminently requires the special qualifications which such an engineer is alone likely to be capable of bringing to bear upon work of such vast importance to the peace and security of the nation.

The Council have had under their consideration the question of the Taxation of Machinery, to which at the last Meeting they invited the attention of the Members of this Institution, to many of whom the subject must be of great importance. For dealing with this matter the National Society for the Exemption of Machinery from Rating has recently been formed; and the Council are glad to take this opportunity of renewing in their corporate capacity the

expression of their cordial sympathy with the object of the Society. The Council urge upon all the Members, who may wish to show their individual interest therein, that they should communicate at once with the Society, from whose office at 22 Buckingham Street, Adelphi, London, W.C., papers and full information will be supplied.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, retire from office this day. The result of the ballot for the election of the Council for the present year will be announced to the Meeting. At the last Meeting the President expressed his regret that he found himself unable from various considerations to accept the nomination for a second year of office. It is scarcely necessary for the Members to be assured with how great regret the Council had previously felt themselves called upon to accept his intimation to this effect, after they had unanimously nominated him for re-election. Mr. Cochrane's energy in devoting himself to the duties of President has been apparent to all the Members who have attended the Meetings under his presidency during the past year. While disappointed however of the advantage of his able guidance in the same capacity during a second year, the Members will share the heartfelt sympathy conveyed to him by the Council, and their warmest wishes for the establishment of his son's health, and for his own consequent relief from an anxiety which has thus prematurely deprived them of a President who has so actively exerted himself for promoting the best interests of the Institution, as also he had already done during so many years previous to his election to the presidential chair.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Printing and Engraving Proceedings of 1889	1,097	7	5			
Less Authors' Copies of Papers, repaid	57	7	6	1,039	19	11
„ Stationery and General Printing				160	17	6
„ Binding				30	19	0
„ Rent				550	0	0
„ Salaries and Wages				1,841	17	3
„ Coal, Firewood, and Gas				24	11	0
„ Fittings and Repairs				21	14	3
„ Postages				292	4	10
„ Insurance				5	2	3
„ Travelling Expenses				5	13	8
„ Petty Expenses				48	11	0
„ Meeting Expenses—						
Printing	242	13	7			
Translations, &c.	30	13	6			
Reporting	80	19	3			
Diagrams, Screen, &c.	89	17	11			
Travelling and Incidental Expenses	133	0	5	577	4	8
„ Dinner Guests				60	12	11
„ Research				182	18	1
„ Books purchased				7	6	4
				4,849	12	8
Accounts owing, not yet rendered, say	600	0	0			
Less Reserve in previous year for accounts since paid	600	0	0	0	0	0
Balance, being excess of Receipts over Expenditure, carried down				1,411	5	7
				£6,260	18	3

To Investment—			
£782 *Metropolitan Railway 4% Debenture Stock*	999	6	4
Cash Balance at this date	2,236	17	3
	£3,236	3	7

FOR THE YEAR ENDING 31ST DECEMBER 1889. *Cr.*

Receipts.

	£	s.	d.	£	s.	d.
By Entrance Fees—						
89 *New Members at £2*	178	0	0			
9 *New Associates at £2*	18	0	0			
23 *New Graduates at £1*	23	0	0			
9 *Graduates transferred to Members at £1*	9	0	0	228	0	0
„ Subscriptions for 1889—						
1453 *Members at £3*	4,359	0	0			
46 *Associates at £3*	138	0	0			
132 *Graduates at £2*	264	0	0			
9 *Graduates transferred to Members at £1*	9	0	0	4,770	0	0
„ Subscriptions in arrear—						
93 *Members at £3*	279	0	0			
5 *Graduates at £2*	10	0	0	289	0	0
„ Subscriptions in advance—						
28 *Members at £3*	84	0	0			
1 *Graduate at £2*	2	0	0	86	0	0
„ Interest—						
From Investments	589	2	3			
From Whitworth Bequest	234	2	6			
From Bank	22	15	9	846	0	6
„ Reports of Proceedings—						
Extra Copies sold				41	17	9
				£6,260	18	3
By Balance brought down				1,411	5	7
Cash Balance 31st December 1888				1,824	18	0
				£3,236	3	7

Dr. BALANCE SHEET

	£	s.	d.
To Sundry Creditors—			
Accounts owing, not yet rendered, say	600	0	0
Capital of the Institution at this date	31,157	7	3
	£31,757	7	3

Signed by the following members of the Finance Committee:—

JOSEPH TOMLINSON.
SIR JAMES N. DOUGLASS.
SIR DOUGLAS GALTON.
ALEXANDER B. W. KENNEDY.

AS AT 31ST DECEMBER 1889. *Cr.*

	£	s.	d.	£	s.	d.
By Cash—*In Union Bank, on Deposit*	1,400	0	0			
„ „ „ *on Current account* . .	336	17	3			
In Imperial Bank . . .	492	11	2			
In hand	7	8	10	500	0	0
				2,236	17	3
„ Investments—(*cost* £17,489 8*s.* 6*d.*)						
£						
3,178 *London & North Western Ry.* 4% *Debenture Stock*						
2,200 *North Eastern* „ „ „ „						
2,466 *Midland* „ „ „ „						
1,800 *Great Western* „ „ „ „						
1,270 *Great Eastern* „ „ „ „						
1,673 *Metropolitan* „ „ „ „						
2,325 „ „ 3½% „ „						
1,000 *Aire & Calder Navigation* „ „ „						
700 *Sir J. Whitworth and Co., Ld.* 5% „ „						
Two hundred £10 *shares Sir J. Whitworth and Co., Ld.*						
The Market Value of these investments at 31*st Dec.* 1889 *was about*				23,452	0	0
„ Subscriptions in Arrear £452, probable value				240	0	0
„ Office Furniture and Fittings				220	10	0
„ Library				1,230	0	0
„ Proceedings, back numbers at cost				4,250	0	0
„ Drawings, Engravings, Models, Specimens, and Sculpture .				128	0	0
				£31,757	7	3

Audited and Certified by

ROBERT A. McLEAN, Chartered Accountant,
1 Queen Victoria Street, London, E.C.

LIST OF DONATIONS TO LIBRARY.

Compound Locomotive Engines, Worsdell and Von Borries' system; from Messrs. Taite and Carlton.

Ironmonger Diary, 1889; from the publisher.

Specifications for Triple-Expansion Twin-Screw Propelling Machinery for U.S. Steamship "Maine"; and Specifications to be followed by Contractors in making Designs for Machinery for the same vessel; from the Bureau of Steam Engineering, United States Navy Department, Washington, U.S.

Report of the Metropolitan Fire Brigade, 1888; from Captain E. M. Shaw.

Illustrated Prospectus of the Westinghouse Electric Company; from the Westinghouse Brake Company.

Report of the Kew Observatory Committee, 1888; from the Committee.

Australian Irrigation Colonies, by J. E. Matthew Vincent; from Messrs. Chaffey Brothers.

Classified List and Distribution Return of Establishment, Indian Public Works Department, to 31 December 1888; ditto to 30 June 1889; from the Registrar.

The following from Mr. E. H. Carbutt:—Purdon's Irish Farmers' and Gardeners' Almanac, 1888; Tenth, Nineteenth, and Twentieth Annual Reports of the Flax Supply Association for the Improvement of the Culture of Flax in Ireland; Handbook on Dairy Factories, Creameries, and Home Dairying, by the Rev. Canon Bagot; Railway Returns for England and Wales, Scotland, and Ireland, 1885; Mining and Mineral Statistics of the United Kingdom, 1886; Second Report of the Royal Commission on Irish Public Works, 1888.

Annual Report of the Chief of the Bureau of Steam Engineering, United States Navy Department, 1888; from the Bureau.

Use of Heavier Rails for Safety and Economy in Railway Traffic, by C. P. Sandberg; with Section of 100 lbs. Steel Rail for Victorian Railways; from the author.

Torpedoes, Torpedo Vessels, and Torpedo Warfare, by Lieutenant W. H. Jaques, late U.S.N.; from the author.

Naval Torpedo Warfare, by Lieutenant W. H. Jaques, late U.S.N.; from the author.

Report of the Second Annual Convention of the National Association of Builders of the United States of America; from the Association.

Modern Railways and Railway Travelling, by William P. Marshall; from the author.

Maximum Discharge through a Pipe of Circular Section when the effective Head is due only to the Pipe's Inclination, by Professor Henry Hennessy, F.R.S.; from the author.

Chemin de fer de l'Est, Notice sur le Wagon d'Expériences, Mai 1878, par L. Regray; from Mr. C. E. Cardew.

Annual Reports of the U.S. Chief of Ordnance, 1888 and 1889; from the Ordnance Office, Washington, U.S.

Address by the Rector of the Royal Technical High School, Berlin, 26 Jan. 1889; from the author.

Catalogue of Pressure Gauges, &c.; from Messrs. Schäffer and Budenberg.

Scientific Works of the late Sir William Siemens, F.R.S. (three volumes), edited by E. F. Bamber; from the Executors.

The following official publications from the Government of New South Wales:—New South Wales Blue Book for 1887; Commissioner's Reports for 1887 and 1888 on the Railways and Tramways of New South Wales; ditto for quarter ending June 1889; Thirty-third Annual Report (1887) of the Postmaster-General. General Report of Parliamentary Standing Committee on Public Works, together with Reports on the following:—Wharfage Accommodation, Woolloomooloo Bay; Improvements to Circular Quay, Sydney; Storage Reservoir at Potts' Hill, and Second Line of Pipes to Crown Street, Sydney; New Central Police Court, Sydney; Drainage Works, Manly; Drainage Works, North Shore; and Harbour Improvements at Newcastle.

Public Works Department Serials, from the India Office:—No. 17, Papers relating to the Sidhnai Canal Project in the Punjab; No. 21, Completion Reports of Public Office Buildings and Clerks' Cottages at Simla.

Modern Cotton Carding Engine, by Joseph Nasmith; from the author.

Ring Spinning Machinery, by Joseph Nasmith; from the author.

Trials of Worthington High-Duty Pumping Engines; from Mr. John G. Mair-Rumley.

Practical Surveying, by George W. Usill; from the publishers.

Practical Use of the Spectroscope, by J. Parry; from the author.

List of Chinese Lighthouses, Light Vessels, Buoys, and Beacons, 1889; from the Inspector-General of Chinese Customs.

Exercises in Graphic Statics, Part I, Roofs &c., by G. F. Charnock; from the author.

Severn Tunnel, its Construction and Difficulties, 1872–1887, by Thomas A. Walker; from the author.

Manual of Metal-Plate Work, by C. T. Millis; from the author.

Technical Instruction for Metal-Plate Workers, by C. T. Millis; from the author.

Ether-Pressure Theory of Thermodynamics applied to Steam, by J. Macfarlane Gray; from the Institution of Naval Architects.

Versnelde Werking van Lucht-Remmen, door Albert Kapteyn; from the author.

Practicable Decimal System for Great Britain and her Colonies, by R. T. Rohde; from the author.

Aperçu Général des Dispositions et Installations de l'Exposition Universelle de 1889, Paris, par M. J. Charton; from the Société des Ingénieurs Civils.

Les Caisses de Secours et de Prévoyance à la Compagnie Houillère de Bessèges, par J. B. Marsaut; from the author.

Mining Manual, by Walter R. Skinner; from the author.

Manufacture of Styrian Open-Hearth Steel, by F. Korb and Thomas Turner; from the authors.

Register of Fellows and Associates of the Institute of Chemistry of Great Britain and Ireland, 1889; from the Institute.

Gemeinfassliche Darstellung des Eisenhüttenwesens; from the German Ironmasters' Association.

Comptes Rendus des Séances des 11e 12e, et 13e, Congrès des Ingénieurs en Chef des Associations de Propriétaires d'Appareils à Vapeur, Paris, 1886, 1887, et 1888; from the Association Belge pour la Surveillance des Chaudières à Vapeur.

Disadvantages of the present Muzzle-Loading system and new Breech-Loading system (with Appendix), by Rear-Admiral Robert A. E. Scott; from the author.

Dictionary of Explosives, by Major J. P. Cundill, R.A.; from the Royal Engineers Institute.

Water Supply for Small Towns and Villages, by R. E. Middleton; from the author.

Principles of Carding Cotton, Card Wire, and Carding Engines, by Benjamin A. Dobson; from the author.

British Iron Trade Report, 1888; from Mr. J. S. Jeans.

Congrès International des Chemins de fer, Paris, 1889, Note sur la question des Primes au Personnel, par A. Borodin; from the author.

The New Tay Bridge, a course of lectures delivered at the Royal School of Military Engineering, Chatham, November 1888, by Crawford Barlow; from the author.

Prospectus of Sydney Technical College, 1888; from Mr. Norman Selfe.

Report of the New South Wales Board of Technical Education, 1888, and Calendar of Sydney Technical College, 1889; from Mr. Norman Selfe.

Presidential Address to Students of Sydney Technical College, 1889, by Norman Selfe; from the author.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Boiler Explosions 1888, by Edward B. Marten; from the author.

Specification of an improved Machine-Tool, chiefly designed for turning Crank-pins of Locomotives; from Mr. Thomas Urquhart.

Graphics, or the Art of Calculation by Drawing Lines, Part I (with atlas of diagrams), by Professor Robert H. Smith; from the author.

Comparative Tables of Wages Rates, 1884–86-88; from Mr. E. Hutchings, Secretary of the General Association of Master Engineers, Shipbuilders, Iron and Brass Founders, &c.

Album of Photographs of some of the Members attending the Dublin Summer Meeting, 1888; from Mr. William Lawrence.

The following from Mr. Charles D'Albert:—Hotchkiss system of Rapid-Firing Guns; Hotchkiss Revolving Cannon, by Lieutenant Edward W. Very, U.S.N.; Description of the 10 centimètre (33-pounder) Hotchkiss Rapid-Firing Gun and Naval Mount; Description of the 65 mm. (9-pounder) Hotchkiss Rapid-Firing Gun; Record of Experiments made with the Hotchkiss Light 47 mm. Rapid-Firing Gun at Shoeburyness, 1883–84; Record of Experiments made with the Hotchkiss Long 47 mm. Rapid-Firing Gun at Sevran-Livry and Gavre, France, 1884; Catalogue of Exhibits of the Hotchkiss Company at the Paris Exhibition, 1889.

Description of Grove's Spray Baths, by David Grove; from the author.

Stevens Institute of Technology, Hoboken, New Jersey, U.S., Exterior and Interior Views; from the Institute.

Municipal Engineering in Hull, by A. E. White; from the author.

Dredging and Dredging Appliances, by Andrew Brown; from the author.

Catalogue of Ship Models and Marine Engineering in the South Kensington Museum; from the Science and Art Department.

Scheme for Junior and Higher Commercial Education; from the London Chamber of Commerce.

Reform in Pyrological Terms and Calculations, by C. J. Hanssen; from the author.

On the relation of the Yard to the Meter; from the Bureau of Weights and Measures, United States Coast and Geodetic Survey Office, Washington, U.S.

Treatment of Steel by Hydraulic Pressure, by William Henry Greenwood; from the author.

Illustrated Catalogue of Railway Safety Appliances; from Messrs. Saxby and Farmer.

Report on Uniform Standard Time, by the Special Committee of the American Society of Civil Engineers; from the Society.

Aeneidea (Vol. III), by Dr. James Henry; from the trustees of the author.

Injectors, by Sidney Boulding; from the author.

Address at a Preliminary Meeting of the Indian Institute of Marine and Mechanical Engineers, by Patrick Doyle; from the author.

Naval Annual, 1888–89; from the Right Honourable Lord Brassey, K.C.B.

Scientific News, Vol. I (old series) and Vols. I and II (new series); from Mr. J. Emerson Dowson.

From the United States Geological Survey.

First Annual Report of the United States Geological Survey, 1880, by Clarence King.

Mineral Resources of the United States, 1882, 1883–1884, 1885, 1886, and 1887.

Bulletins of the United States Geological Survey, Nos. 1–47.

The following eleven Monographs of the Survey:—

II. Tertiary History of the Grand Cañon District (with atlas), by Clarence E. Dutton.

III. Geology of the Comstock Lode and Washoe District (with atlas), by George F. Becker.

IV. Comstock Mining and Miners, by Eliot Lord.

V. Copper-Bearing Rocks of Lake Superior, by Roland D. Irving.

VI. Contributions to the knowledge of the Older Mesozoic Flora of Virginia, by William M. Fontaine.

VII. Silver-Lead Deposits of Eureka, Nevada, by Joseph S. Curtis.

VIII. Paleontology of the Eureka District, by Charles D. Walcott.

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield.

X. Dinocerata, an Extinct Order of Gigantic Mammals, by Othniel C. Marsh.

XI. Geological History of Lake Lahontan, North-Western Nevada, by Israel C. Russell.

XII. Geology and Mining Industry of Leadville, Colorado (with atlas), by Samuel F. Emmons.

Notes on the Construction of Ordnance; from the Ordnance Office, Washington, U.S.

Railway Workshops, their Design and Construction, by J. Davis Barnett; from the author.

Heat Engines other than Steam, by H. Graham Harris; from the author.

Civil and Mechanical Engineering, popularly and socially considered, by J. W. C. Haldane; from the author.

Statistical Review of Financial and Agricultural Results obtained in 1887–88 from the Irrigation Works of India; from Mr. R. B. Buckley.

Illustrated Catalogue of Tools and Machinery, &c.; from Messrs. Buck and Hickman.

Groves' and Thorp's Chemical Technology, Vol. I, Fuel and its Applications, by Dr. E. J. Mills, F.R.S., and F. J. Rowan; from the publishers.

Album of Working Drawings of St. Petersburg built 8-wheeled Locomotives; from Mr. Thomas Urquhart.

Catalogue of Water-Works Constructional Articles &c.; from Messrs. Guest and Chrimes.

Cornell University Register, 1888-89; from the University.

Engineer's Annual Report, 1889, as to the Progress of the Vyrnwy Waterworks, by George F. Deacon; from the author.

Report (Parts I and II) of Royal Commission to enquire into the Sanitary Condition of Melbourne; from the Commission.

Continuous Brakes, by H. Graham Harris; from the author.

Channel Bridge, Preliminary Designs of Messrs. Schneider and Co. and H. Hersent; from the Iron and Steel Institute.

Worthington High-Duty Pumping Engine at the Paris Exhibition, 1889; from the Worthington Pumping Engine Company.

The following from Mr. Henry Chapman:—Note sur les Chaudières tubulaires, marines ou autres, à très haute pression (système A. Lagrafel et J. d'Allest); Notice sur la Panclastite, nouvelle section d'Explosifs découverte par Eugène Turpin; Report of Mr. William Parker's Visit to Steel Manufacturing and Engineering Works in France; Rapport fait par M. le Colonel Pierre sur le Pont à Bascule de M. P. Guillaumin; Notice sur la Construction d'un Pont à Bascule (système Guillaumin); Description of Perreur-Lloyd's Generators; Sidérurgie, Exposition Universelle de 1889, Paris, par G. Bresson; L'Industrie sidérurgique à l'Exposition Universelle de 1889, Paris.

The Coal Question, by R. Price-Williams; from the author.

Planimeter and Totalling Rule; from Mr. William W. Girdwood.

Answer to certain Chapters in the Rev. A. B. Bruce's "Life of William Denny," by Saturnino Ribes; from the author.

Five Months' Fine Weather in Canada, Western United States, and Mexico, by Mrs. E. H. Carbutt; from the author.

Illustrated Catalogue of Engineering Department of the Hull Cart and Wagon Company; from Mr. W. R. Harrison.

Electrical Transmission of Power in Mining Operations, by Albion T. Snell; from Messrs. Immisch and Co.

Liquid Fuel for Mechanical and Industrial Purposes, by E. A. Brayley Hodgetts; from the author.

Prize Essay on the Suspension of Carriages, by William Philipson; from the author.

Treatise on the Metallurgy of Iron, by Hilary Bauerman; from the author.

Report on the Canalization of Rivers, and the different systems of Movable Weirs, by L. F. Vernon-Harcourt; from the author.

Spon's Engineers' and Contractors' Diary and Reference Book, 1890; from the publishers.

Magnetic and other Physical Properties of Iron at a High Temperature, by Dr. John Hopkinson, F.R.S.; from the author.

Map of Queensland Water-Supply Department Artesian Bores, with Table of Bores completed; from Mr. John B. Henderson.

Tests of Metals &c. made at Watertown Arsenal, Massachusetts, 1886 (Parts I and II) and 1887; from the Ordnance Office, Washington, U.S.

Civil Engineer's Pocket Book for 1889, by John C. Trautwine; from Mr. John C. Trautwine, Jun.

Calendars for 1889–90 from the following Colleges:—City of London College; Firth College and Sheffield Technical School; Glasgow and West of Scotland Technical College; Royal Technical High School, Berlin; University College, Bristol; University College, Dundee; University College, Liverpool (Department of Engineering); Yorkshire College, Leeds.

Repertory of Patent Inventions, 52 vols., 1834–1862 (with some exceptions); from Mr. Alfred Carpmael, through Sir Frederick J. Bramwell, Bart.

Catalogue of the Guildhall Library of the City of London, 1889; from the Library Committee of the Corporation of the City of London.

Transactions of the North Staffordshire Institute of Mining and Mechanical Engineers, vols. I–VI, 1873–1881; from Mr. Charles Lloyd.

The following Publications from the respective Societies and Authorities:—

Reports of the Academy of Science, France.

Reports of the Royal Academy of Science, Belgium.

Reports of the Royal Institute of Engineers, Holland.

Engravings from the École des Ponts et Chaussées, Paris.

Annales des Ponts et Chaussées, Paris.

Proceedings of the French Institution of Civil Engineers.

Journal of the French Society for the Encouragement of National Industry.

Reports of the French Association for the Advancement of Science, 1887 and 1888.

Annales des Mines.

Annales du Conservatoire des Arts et Métiers.

Journal of the Marseilles Scientific and Industrial Society.

Proceedings of the Engineers' and Architects' Society of Canton Vaud.

Proceedings of the Engineers' and Architects' Society of Austria.

Proceedings of the Architects' and Engineers' Society of Hannover.

Proceedings of the Engineers' and Architects' Society of Prague.

Proceedings of the Italian Engineers' and Architects' Society.
Proceedings of the Engineers' and Architects' Society of Milan.
Proceedings of the Industrial Society of St. Quentin et de l'Aisne.
Proceedings of the Industrial Society of Mulhouse.
Proceedings of the Industrial Society of the North of France.
Proceedings of the Industrial Society of Rouen.
Proceedings of the German Society of Engineers.
Proceedings of the Russian Imperial Institute of Engineers.
Proceedings of the Swedish Society of Engineers.
Journal of the Norwegian Technical Society.
Journal of the Franklin Institute.
Transactions of the American Society of Civil Engineers.
Transactions of the American Society of Mechanical Engineers.
Transactions of the American Institute of Mining Engineers.
School of Mines Quarterly, Columbia College, New York.
Report of the Smithsonian Institution.
Report of the Master Car-Builders' Association, New York.
Proceedings of the United States Naval Institute.
Transactions of the Canadian Society of Civil Engineers.
Proceedings and Journal of the Asiatic Society of Bengal.
Proceedings of the Institution of Civil Engineers.
Journal of the Iron and Steel Institute.
Transactions of the Society of Engineers.
Journal of the Institution of Electrical Engineers.
Transactions of the Institution of Civil Engineers of Ireland.
Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Transactions of the Chesterfield and Midland Counties Institution of Engineers.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Proceedings of the Cleveland Institution of Engineers.
Transactions of the Mining Institute of Scotland.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Transactions of the Hull and District Institution of Engineers and Naval Architects.
Proceedings of the Royal Society of London.
Proceedings of the Royal Institution of Great Britain.
Transactions of the Surveyors' Institution.
Transactions of the Sanitary Institute of Great Britain.
Journal of the Royal United Service Institution.

Professional Papers of the Royal Engineers Institute.
Proceedings of the Royal Artillery Institution.
Journal of the Royal Agricultural Society of England.
Journal of the Royal Statistical Society.
Report of the British Association for the Advancement of Science.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Transactions and Journal of the Royal Institute of British Architects.
Transactions of the Gas Institute.
Proceedings of the Physical Society of London.
Proceedings of the Literary and Philosophical Society of Manchester.
Transactions of the Manchester Geological Society.
Journal of the Royal Scottish Society of Arts.
Proceedings of the Philosophical Society of Glasgow.
Transactions and Proceedings of the Royal Irish Academy.
Transactions and Proceedings of the Royal Dublin Society.
Journal of the Liverpool Polytechnic Society.
Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Proceedings of the Society of Architects.
Transactions of the Manchester Association of Engineers.
Report &c. of Eighth Session of the Junior Engineering Society.
Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.
Midland Steam Boiler Inspection and Assurance Company, Records of Boiler Explosions in 1882, 1883, and 1887; from Mr. Edward B. Marten.
Report of the National Boiler Insurance Company; from Mr. Henry Hiller.
Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.
Eleventh Annual Report of the National Association of British and Irish Millers; from the Association.
Report of the London Association of Foremen Engineers and Draughtsmen.
Sixth Annual Report of the Barrow-in-Furness Free Public Library.
Twenty-seventh Annual Report of the Cardiff Free Library.
Thirty-sixth Annual Report of the Liverpool Free Public Library.
Thirty-seventh Annual Report of the Manchester Public Free Libraries.
Eighth Report of the Newcastle-upon-Tyne Public Libraries Committee.
Catalogue of Additions to the Radcliffe Library, Oxford, during 1888.

The following Periodicals from the respective Editors :—

Revue générale des Chemins de fer.
Revue universelle des Mines.
Revue industrielle.
Stahl und Eisen.
Der Civil-Ingenieur.
Glaser's Annalen.
Giornale del Genio Civile.
Ingeniero y Ferretero Español y Sud Americano.
The American Engineer.
The American Manufacturer.
The Engineering and Mining Journal.
The National Car and Locomotive Builder.
The Railroad and Engineering Journal.
The Railway Master Mechanic.
The Indian Engineer.
Indian Engineering.
The Engineer.
Engineering.
The Railway Engineer.
The Marine Engineer.
Iron.
The Iron and Coal Trades Review.
Ryland's Iron Trade Circular.
The Ironmonger.
Ironmongery.
The Mechanical World.
The Mining Journal.
The Colliery Guardian.
The Machinery Market.
The Builder.
The Builders' Weekly Reporter.
The Electrician.
The Electrical Review.
The Chamber of Commerce Journal (from Mr. Henry Chapman).
The Contract Journal.
The Gas and Water Review.
The Gas World.
The Plumber and Decorator.
The Shipping World.
The Steamship.
The Fireman.
Industries.
Invention.
The Railway Record.
The British Trade Journal.
The Practical Engineer.
Electrical Plant.
Mechanical Progress.
Martineau and Smith's Hardware Trade Journal.
Phillips' Monthly Machinery Register.

The CHAIRMAN invited discussion upon the Annual Report of the Council, which it would be seen indicated that the Institution of Mechanical Engineers had in no wise abated its energy, but on the contrary presented evidences of increased activity and prosperity.

No Member having any remarks to make, he moved that the Report and accounts be adopted, which was agreed to.

The CHAIRMAN announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected :—

PRESIDENT.

JOSEPH TOMLINSON, ...	London.

VICE-PRESIDENTS.

DANIEL ADAMSON, ...	Manchester.
SIR JAMES RAMSDEN, . . .	Barrow-in-Furness.

MEMBERS OF COUNCIL.

SIR DOUGLAS GALTON, K.C.B., F.R.S.,	London.
JOHN HOPKINSON, JUN., D. Sc., F.R.S.,	London.
SAMUEL W. JOHNSON, . . .	Derby.
WILLIAM LAIRD, ...	Birkenhead.
EDWARD P. MARTIN, . . .	Dowlais.

The CHAIRMAN said the Members were aware that, since the issue of the ballot lists for this election, they had lost their Vice-President, Mr. Daniel Adamson, a man of great and distinguished position, whose loss would be felt not only by the engineering profession but by the nation at large.

The Members had also heard of the cause of the retiring President's absence ; and he was sure they would all join in hoping that the voyage he had undertaken would tend to restore his son to health. At the request of the Council, he had been occupying the chair at the commencement of the present Meeting ; and perhaps it was not altogether unfortunate that he had done so, because he could say of the retiring President that which he himself of course could not have said. He had known Mr. Charles Cochrane for many years, in fact ever since they had been at college together ; and in those days he had exhibited that amount of energy and application which had resulted in a distinguished college career, and had given promise of future prosperity and greatness. That promise had been fully realized, for he did not suppose there was any engineer who stood higher than Mr. Cochrane, especially in his own peculiar line. His success

had been crowned by the high position to which he had been elevated by the Members of the Institution of Mechanical Engineers in making him their President. He was quite sure that all those who had attended the meetings of the Institution were fully alive to the discretion and judgment with which their President had conducted them; but it was only the members of the Council who could fully appreciate the tact and good feeling which he had shown, in not only making himself thoroughly conversant with the business of the Institution, so as to be able to conduct the Council meetings in the best possible manner, but also in guiding the deliberations so that harmony might prevail throughout. On that account they all regretted very much that he had found himself unable to accept a second year of office, which he was quite sure would have been conferred upon him by the Members. At the same time they were fortunate in having a successor who was well known to them all as one who had taken a deep interest in the affairs of the Institution, who had been indefatigable in his attendance at the Council meetings and the General meetings, and who had rendered the Institution invaluable aid in connection with the various Research Committees with which he had been associated. Although therefore it had often been said that it was not safe to prophesy before the event was fulfilled, he was confident that on this occasion he might venture to predict that the prosperity of the Institution would in no wise lag behind in the hands of the President elect. In now inducting Mr. Tomlinson into the chair, he was sure that he was speaking for the whole of the Members in wishing him all prosperity and happiness.

Mr. JOSEPH TOMLINSON, President elect, on taking the chair, thanked the Members of the Institution most sincerely for the honour they had conferred upon him in electing him their President. He was himself an old Member of the Institution, having joined it thirty-three years ago; and he had throughout taken all the interest he possibly could in its welfare. For the last ten years he had been a fairly regular attendant at all the Council and Committee meetings;

(The President.)

and though these certainly occupied a considerable amount of time, neither himself nor his colleagues begrudged it. Somebody must do the work, and those who were in the neighbourhood of London, like himself, were prepared to take the lion's share. Until perhaps the last year or two, the honour now conferred upon him had been wholly unlooked for. In the earlier part of his connection with the Institution he had entertained no expectation of being called to so important an office. So far as concerned conducting the business of the Institution, he did not anticipate that with his present colleagues on the Council he should have any more trouble in doing so than his predecessors in the presidency had experienced. To the best of his knowledge they had all worked as harmoniously as it was possible for any Council to do; and he was confident that the same cordial assistance would be rendered to himself as he had always endeavoured to render to preceding presidents. As far as the business of the presidency was concerned, he should endeavour to do his best, in the hope that on rendering up his office the Institution would be in as flourishing a condition as it now was, with its credit as good and its position untarnished.

The announcement just made of the annual election of officers for the present year had included the name of Mr. Adamson, Vice-President, whose death, as the Members were aware, had occurred since the issue of the ballot lists early in the present month. It was now nearly fifty years ago that he had himself begun his engineering life in the same shop at Shildon as Mr. Adamson, who however had already been there a few years earlier. During that time he had always respected him as being a blunt outspoken truthful man, strong in temper perhaps, but having the determination to do that which he felt to be right. The Institution he thought had never lost any member of Council whose removal would be more felt by the Members, and by the engineering profession throughout the world. At their meeting this afternoon the Council had directed that a letter of condolence should be sent to Mrs. Adamson from the President, expressive of their heartfelt sympathy under her recent bereavement, and also of their deep regret at the death of their distinguished colleague.

Mr. JEREMIAH HEAD, Past-President, was sure the Members would all join him in feeling the utmost confidence that the business of the Institution for the next year would be ably and efficiently conducted by their new President. Whilst however gratitude had been humorously defined as "a lively sense of favours to come," there was an older and a truer signification belonging to the term, namely "a lively appreciation of favours received in the past." He had accordingly risen for the purpose of moving "That the best thanks of the Institution be and are hereby given to the ex-President, Mr. Charles Cochrane, for the ability, tact, and unvarying courtesy, with which he has fulfilled the duties of the presidential chair during the past year." He was exceedingly sorry that Mr. Cochrane was not present to receive in person this vote of thanks. The Members had heard the reason why he had been obliged to go away, and at the present time he was probably somewhere in the southern hemisphere. He earnestly hoped that in due course he would return with his own health and that of his son perfectly restored; for he was sure that the Members of this Institution and the engineering profession generally were not able to spare him permanently. Attention had been called by Mr. Anderson to the manner in which Mr. Cochrane had fulfilled the duties of the chair at the general meetings. The Members themselves were all judges of how ably those duties had been fulfilled: they well knew the ability, the experience, the insight, the tact, and the industry, which he had so fully manifested at every meeting over which he had presided. They had witnessed a special instance of his indomitable energy in that he had produced within the space of half a year two excellent papers: one the presidential address, in which he had touched upon a large number of subjects of great interest to engineers; and the other a paper in which he had made known much of his recent valuable and original experience in the working of blast-furnaces. In that department of engineering, which he had made so especially his own, he had been spoken of by Mr. Anderson as being at the top of the tree. As a Clevelander he could well confirm that representation. Mr. Cochrane had been the first practically to apply regenerative stoves to the blast-furnace; and it was generally admitted that with similar materials and up to the

(Mr. Jeremiah Head.)

present time his furnaces were worked with less fuel per ton of pig-iron made than those of any other ironmaster. He had also distinguished himself by his readiness at all times to give to the engineering profession the results of his hard-earned experience, to profit by as much as they chose. Mr. Anderson had also stated that, while the Members were judges of Mr. Cochrane's ability in the chair, and of the services he had rendered at the general meetings, they could not be such judges as the Council were of the ability, the tact, and the urbanity, which he had displayed in equal degree at the Council meetings. He was quite sure that the working staff of the Institution had felt the benefit of his unfailing assiduity, his constant care, and the deep interest he had taken in the affairs of the Institution throughout his term of office. He would now invite the Members to record their approval of the resolution which he had proposed, offering the best thanks of the Institution to Mr. Cochrane for his services as President during the past year.

Mr. ANDERSON cordially endorsed every word that had been uttered by Mr. Head, and had great pleasure in seconding the resolution which had been proposed.

The vote of thanks to the ex-President was passed unanimously.

The PRESIDENT reminded the Members that at the present meeting the appointment had to be made of an Auditor for the present year.

On the motion of Mr. JAMES PLATT, seconded by Mr. E. B. ELLINGTON, it was unanimously resolved that Mr. Robert A. McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the present year, at a remuneration of Ten Guineas, being the same as heretofore.

In pursuance of the notice given at the previous General Meeting, the three following new By-laws were proposed from the chair on behalf of the Council :—

"Any Member or Associate whose subscription is not in arrear may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds. All compositions shall be deemed to be capital moneys of the Institution."

"The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following :—for Members, M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E."

"Subject to such regulations as the Council may from time to time prescribe, any Member, Graduate, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution."

The PRESIDENT said the proposal with regard to Life Composition had been brought forward by the Council in consequence of several applications having been received from Members for an opportunity to compound. The subject had been carefully gone into by the Council in all its bearings, and the proposed By-law was the result of their deliberations.

No remarks being offered by any of the Members present, the first new By-law was unanimously agreed to.

With regard to the abbreviated distinctive Titles in the second proposed By-law, the PRESIDENT pointed out that the letter M might apply also to Mining and Marine engineering; and the Council had therefore thought it better to recommend the abbreviation "Mech" for rendering the title quite distinct.

No remarks being made by any Member present, the second new By-law was unanimously agreed to.

(The President.)

In proposing the third new By-law, the PRESIDENT referred to the well known practice of many other societies to grant Certificates which Members might hang up in their offices, so as to show their connection with those societies. Up to the present time no such badge of membership had been adopted by the Institution of Mechanical Engineers, and it had been suggested that this should now be done. If the Members approved of the proposal, the Council would proceed to draw up a suitable form of diploma, with which any Member would then be furnished on application; and any suggestions on the subject would be welcome.

Mr. W. SCHÖNHEYDER asked why the certificate was to remain the property of the Institution, and be returned to the Institution if required.

The PRESIDENT explained that in the absence of this condition any one ceasing to be a member of the Institution might still keep and use the diploma. On ceasing to be a member however, he would have no right to use the certificate of the Institution.

The third new By-law was then unanimously agreed to.

Mr. BENJAMIN A. DOBSON, Member of Council, proposed the following Resolution, in pursuance of the notice he had given at the previous General Meeting:—"That the President be requested to convey to the National Society for the Exemption of Machinery from Rating the hearty sympathy of this Meeting with the object of the Society."

This resolution he thought might well be considered as coming within the legitimate scope of the Institution, inasmuch as one of the objects for which the Institution was established was declared in the articles of association to be "to promote the science and practice of Mechanical Engineering and all branches of mechanical construction." In order to understand the bearing of the resolution now proposed, he might explain that for some years past, and particularly during the last five years, there had been manifested an extraordinary energy on the part of rating authorities in endeavouring to extend the area of rating over certain classes of machinery and plant which had hitherto been exempted. Up to the commencement of that movement, the universally understood principle upon which the extent of rating was decided by the authorities might be said in few words to have been—"the freehold is rateable to the poor, the tenancy is exempt." This principle was easy of comprehension, and the line between rateable and unrateable property was strongly marked. Unfortunately a dispute had arisen in the north-east of England as to whether certain machinery used in the ordinary practice of shipbuilding was rateable. There could be little doubt that in the trial of that case at the quarter sessions, and subsequently during the various appeals, it had been clearly proved that the machinery in question was so situated as to be, as was said in Lancashire, "fastened to the freehold." For some reason, respecting which he was entirely in the dark, that case had been made a test case; and in a subsequent case, which dealt with an ordinary general engineering establishment, the decision in that previous case had had a great effect upon the minds of the judges; and the action of an old law, the extent of which had been expressly limited, had become enormously increased, and, as a matter of fact, had now been made to include everything within the four walls of the establishment. Having examined a certified copy of the assessor's

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rate book, he had found that on the last page of that book there was entered certain of the office furniture, and one of the last items he believed was a nest of drawers to contain drawings. It was scarcely necessary to point out the absurdity of including such an item, or the grosser absurdities which would most certainly arise, were that injurious principle extended generally. The textile industries would be especially weighted: bootmakers, dressmakers, where sewing machines were employed, and hosiery manufacturers; joiners, builders, and even agriculturists. No trade would escape; and if the principle were carried out thoroughly and logically, the poor seamstress would be obliged to pay towards the relief of the poor on the value of the sewing machine she possessed. Manufacturing engineers would also be heavy losers, as the Members of this Institution could well calculate for themselves. His reasons for inviting the present Meeting to express an opinion in the terms of his motion were:—firstly, that, unless the law were rightly defined, mechanical engineers would be heavily and unfairly weighted by taxation in the conduct of their ordinary business; secondly, that progress would be hindered and improvements delayed, and our insular industries placed at a disadvantage in relation to foreign competition, unless the risk was removed of having to pay extra taxation on all attempts to economize production; and thirdly, that any extension of the principle of rating all plant and machinery, irrespective of its being fixed or removable, would most assuredly tend to discourage the purchase and use of improved means of economical production. If these reasons were considered good and sufficient, the Meeting he thought might vote for the motion in the interests of the promotion of mechanical construction; and as the National Society for the Exemption of Machinery from Rating had for its sole object the definition of a law and the redress of a wrong, mechanical engineers should in their own interests afford that Society their moral support.

Mr. HENRY D. MARSHALL, Member of Council, in seconding the motion, said that, after the clear and explicit way in which the subject had been brought before the Meeting by Mr. Dobson, there were only one or two points to which he would himself draw

attention. Throughout all the manufacturing centres of this country the practice had hitherto been not to rate machinery. The general rule had been that whatever passed with the freehold was rateable; and it had been the practice to assess fixed steam-engines and shafting, which constituted the motive power. It would be a serious question however for every manufacturing engineer if his tools and machinery were to be capitalized and made rateable. It might just as well be said that the furniture of a house gave the walls their rateable value, namely their occupation value, as that machinery gave to premises their occupation or rateable value: which was undoubtedly the fact, because with bare walls no business could be conducted. But if the machinery were capitalized and made rateable, it would be fatal to the engineering industry. Many years ago the law had been settled by the case of Messrs. Courtauld's silk and crape works at Halstead. Then there had followed two northern cases which had rather reversed the decision; and in certain exceptional cases machinery had been rated. Lately there had been a decision in the Scotch court of session by Lord Fraser, which had again put the law on a footing that he hoped would be regarded as right and reasonable, namely that freehold buildings and fixed engines (that is, motive power and shafting) should alone be rateable. It had probably come under the notice of the Members that during the last three or four sessions of parliament a bill on the subject had been introduced; but in the present age of progressive legislation it had been considered a minor bill. To manufacturers however it was a very important bill; and it set forth what he considered the correct and proper principle of rating, as just defined. If the principle of rating machinery was allowed to be altered, it would alter entirely the incidence of rating throughout the country. If the furniture of a house or office were to be rated, as mentioned by Mr. Dobson, the seamstress's sewing machine and the watchmaker's lathe would have to be rated, all on the same basis; but that could not be a fair and reasonable interpretation of what was to be assessed. Taking the main definition of rateable machinery to be what passed with the freehold, this was the principle which had formerly been laid down, and was the only just and reasonable one that could be accepted.

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By every means in their power, as mechanical engineers or manufacturers of any kind, he hoped that the Members would do all they could to repel increase of taxation in this direction, which he regarded as likely to prove almost fatal to the manufacturing industry of the country.

Mr. JAMES PLATT had much pleasure in supporting the resolution. The Society therein referred to had been formed for the purpose of promoting legislation on the subject. At present the interpretations of the law by different judges were at variance, and it was therefore highly important that legislation should take place. There was as yet no act of parliament which could be referred to on this important question; and there were certain professional valuers going about the country, who went to the overseers with the offer that for a commission of so much per cent. they would increase the rateable value. In the south-west of England the question had been warmly taken up of late. At Chard, in Somersetshire, the assessment of a lace factory had been raised from £290 up to £895; and when the matter was brought into court, the increase had been defended on the plea that it was not the machinery which was being rated, but that the premises themselves were worth so much more by reason of the machinery they contained. This seemed to him to be a distinction without a difference. The Chard case had been taken up by the Society referred to in the resolution, and was being carried to the House of Lords. The great aim however was to promote legislation, which was really a very important object. As Mr. Dobson and Mr. Marshall had said, it would make a serious difference to manufacturers if all machinery were rated; and as a large number of the Members of the Institution were manufacturers, it was a serious subject for them, and he thought any help they could give ought to be given in the direction of exempting machinery from rating. It might be supposed that if all machinery were rated, the rate would probably be lightened; but it would have the effect of altering the incidence of taxation, and would be putting a burden upon manufacturers, and relieving the land-owners or landlords at the expense of the manufacturers. At present

however the assessors were still wanting as high a rate as ever, although they were extending the rating of machinery in various directions. It need not be expected therefore that the rate would become much lighter, even if the assessment of machinery became general.

Mr. JEREMIAH HEAD, Past-President, said that the principle enunciated by Mr. Marshall—namely that the rateable value should be merely that of the buildings and the engine power and the shafting, or all that passed with the freehold—seemed to be clear and intelligible with regard to such places as cotton mills and factories of a similar description. But there were many manufacturing premises where every machine had its own engine attached to it: as in the case of the punching and shearing machines and most of the other machinery employed in manufactured-iron works, ship-building yards, and similar establishments. There the fashion now was to have heavy machines in various places, connected by steam-pipes only, every machine having its own engine. The principle that the engine power and shafting should pass with the freehold had evidently been founded in the first instance on the idea of a cotton mill, or some factory of that kind; but this was now by no means the type of all the manufacturing premises in the country. It appeared to him that where heavy trades were carried on the fashion was increasing for every machine to have its own engine. He mentioned this matter, not as a contradiction of anything that had been said, because he had a great deal of sympathy with the speakers who had already stated their views; but merely to show that the question at issue was a difficult one. It was but little understood, and certainly not at all understood among lawyers. Contradictory decisions had been frequently given, and the whole subject was in a state of perplexity, which seemed to want investigation first and then legislation. There was a difference of opinion, for instance, as mentioned by Mr. Dobson, as to what was fixed and what was loose. In some iron-works there were thousands of pounds' worth of cast-iron floor-plates on the premises. He had known these regarded by some legal authorities as not being fixed, but partaking of the nature of a carpet, which

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could be taken up. He had also known them regarded by others of equal authority as absolutely fixed, because without them nothing could be moved about. This showed how much uncertainty existed as to what constituted rateable property. With regard to heavy tools, many of them were now not fixed down at all; their own weight kept them firmly in position. The distinction of being fixed or not fixed was all very well as between a brick building and a wooden shed or similar temporary structure; but it was not a proper distinction as between one machine and another.

Mr. HENRY DAVEY pointed out that another complication often arose in the rating of machinery, namely that one parish got relieved at the expense of another. The poor-law board frequently had jurisdiction over several parishes, one of which might contain a large number of manufactories, while the adjoining parish might be almost exempt from them: so that, if machinery was to bear the major part of the charge, the parish in which the machinery was situated would be heavily rated, to the relief of the adjoining parish. An instance of that kind had occurred some years ago in Leeds, showing that the law, or the want of law as the matter stood at present, was attended with a variety of complications.

The PRESIDENT said it was proposed to take a very important step by means of legislation; and the subject should therefore be as well ventilated as possible.

Mr. MARSHALL mentioned that a special committee of the House of Commons had been appointed to look carefully into this question; and it was upon their report that the bills had been based which had been introduced in the last two sessions and crowded out. After a most exhaustive research upon their own part, and an examination of some of the most capable engineering and other witnesses in the country on both sides, the committee had clearly set forth what ought to be rated—namely the freehold buildings, the fixed motors, and the shafting; and they had clearly and practically defined what by usage passed with the freehold. In every case that had come under his

knowledge where a concern had been broken up, goods and chattels, although bolted to the freehold, had been sold by auction; and if they were mortgaged, a special bill of sale had been required. He therefore maintained that the only proper and reasonable way of propounding the law was in the form of the enquiry—what would the premises let for, when used for the purposes for which they were occupied? As the question had been so exhaustively gone into by the committee of the House of Commons, who had established the above as a reasonable and proper interpretation of the law, he thought it behoved all mechanical engineers as manufacturers to do their utmost to carry the proposed bill; and to oppose any legislation in contravention of it, which would really mean assessing the manufacturing community in an improper and unjust manner and to the advantage of others.

Mr. DOBSON said he had himself been to a certain extent instrumental in helping to prepare the bill to which reference had just been made. The act of parliament upon which the rating was now fixed had been passed he believed in the reign of Queen Elizabeth, and it was evident that at that time the conditions of every-day life were entirely different from the present. It could not have been foreseen by any one at that time that the present state of complication of manufacture would afterwards be reached. He had taken up the question as a manufacturing engineer, because he maintained, as he had already stated, that any tax of this kind would assuredly reduce the amount of machinery to be manufactured. If a manufacturer knew that if he purchased certain machinery or a certain tool it would be assessed in the rate books at fifty pounds, upon which he would have to pay two or three shillings in the pound, he would think twice before he purchased the machinery or the tool. At present he knew that if he purchased it he had only its ordinary depreciation to allow for; but if the new principle were extended, as it was being extended every day by enterprising valuers, the result would be that people would be discouraged from making purchases of machinery, and thereby improvements would be delayed. He trusted that the explanations which had been given would be

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sufficient to secure the unanimous acceptance of the resolution he had proposed.

Mr. ARTHUR PAGET, Vice-President, heartily supported the resolution, but on somewhat different grounds from those on which it had been supported by previous speakers. The principle of rating adopted for many hundreds of years had clearly been that in all classes of property that which appertained to the freehold, and that alone, was rateable to the poor. He supported the resolution because he thought the Institution would in that way be stepping in to prevent a gross injustice. One class of property which did not pertain to the freehold was being increasingly taxed year by year, whereas other properties of an exactly similar nature were not taxed. The resolution would encourage a very useful Society in bringing about legislation that should prevent incongruous and unjust interpretations of the law. There was no reason why taxation should be imposed upon machinery, when other things which increased the value of property, but which did not belong to the freehold, were not taxed. He was exceedingly thankful to find the Institution taking the step now proposed, which he considered was a step well within the scope of the objects of the Institution, and a step in the right direction; it differed entirely from what had been done hitherto, and he therefore heartily welcomed it. The Institution he thought had been attending to pure abstract science, pure abstract mechanics, and doing remarkably little for the material interests of the engineers of whom it was formed. By passing the resolution, which he hoped they would do with absolute unanimity, the Members would be taking care of the interests of their own profession, and doing that which he should be glad to see the Institution do thoroughly in other directions.

Mr. W. D. SCOTT-MONCRIEFF suggested that any Members of the Institution who were also members of the National Society for the Exemption of Machinery from Rating might possibly use their influence in obtaining from that Society the information which was no doubt in its possession in regard to legal decisions and other

matters, in a succinct form for the benefit of the Members of this Institution. No doubt the Society was anxious to obtain all possible assistance; and it would be a good thing if the necessary information could be placed in the hands of Members of the Institution, in the event of the subject coming up for discussion elsewhere.

Mr. JAMES PLATT pointed out that the best way of obtaining the desired information was to become a subscriber to the Society, all the members of which were kept posted up with all the information as it was obtained. He recommended that all manufacturers should subscribe to the Society.

Mr. E. B. ELLINGTON observed, with a view of obtaining a unanimous vote, that the resolution only committed the Meeting to the moral support of the National Society. It was not intended, he presumed, that this Institution should take part in the propaganda of the Society; there might be a difference of opinion on that point, but not as to the desirability of giving the support of an expression of sympathy with the object of the Society.

Mr. HEAD noticed that attention had been called by Mr. Marshall to a certain parliamentary report, in which there was a recommendation that the motive power and the shafting should be rateable as going with the freehold. His own reason for referring to heavy machines was that motive power in many cases had nothing to do with the freehold. Often the motive power was attached to the machines themselves, and not at all to the freehold; and he thought the engineering authorities consulted by the parliamentary committee could scarcely have considered cases of this kind. The conclusion which he believed would be arrived at was that no machinery, not even motive power, should be subject to be rated; but that all machinery, motive power, shafting, and so on, should be exempted from taxation.

Mr. DOBSON said that was what the bill aimed at. The object of the bill was to tax the freehold and nothing else; and it was intended

(Mr. Benjamin A. Dobson.)
to exempt machines which were not part of the freehold, and heavy machines which had their own motive power.

Mr. JOHN ETHERINGTON regretted that there were not more Members present from Nottingham. The question was one affecting Nottingham manufacturers seriously, for at the present time a movement was on foot in Nottingham for the rating of all the lace machines, even in the midst of the existing great depression of trade. The Nottingham Members he thought had lost a good opportunity in not being more numerously represented at this Meeting to protect their own machines and interests.

The PRESIDENT thought no one could disagree with the views expressed by the proposer of the resolution, that there should be something like definite legislation on this subject. Manufacturers in different parts of the country were being treated differently, and mechanical engineers were therefore quite right in advocating the views expressed by Mr. Dobson. Whether the Members would be right in interfering as an Institution with matters of political economy was another question, with which for himself he did not agree. The expression of opinion on the part of the Members present, whatever it might be, would of course go forth as the opinion of this Meeting only, not of the Institution; because the Meeting could not express the opinion of the Institution on a question of political economy. He had now much pleasure in putting the motion.

The resolution was unanimously adopted.

The following Paper was then read and partly discussed:—

On the Compounding of Locomotives burning Petroleum Refuse in Russia; by Mr. THOMAS URQUHART, of Borisoglebsk, Russia.

At Half-past Nine o'clock the Meeting was adjourned till the following evening. The attendance was 74 Members and 37 Visitors.

The ADJOURNED MEETING of the Institution was held at the Institution of Civil Engineers, London, on Thursday, 30th January 1890, at Half-past Seven o'clock p.m.; JOSEPH TOMLINSON, Esq., President, in the chair.

The PRESIDENT announced that, in accordance with the Articles of Association of the Institution, the two vacancies amongst the Vice-Presidents, which had been caused by the election of himself as President and by the lamented death of Mr. Daniel Adamson, had now been filled up by the Council by the appointment of the two following Members of Council as Vice-Presidents:—Professor Kennedy and Mr. E. Windsor Richards. For supplying the consequent vacancies amongst the Members of Council, the Council had endeavoured to give effect to the wishes of the Members by appointing Mr. William Henry Maw and Mr. William Henry White, F.R.S., their names being the two next in order in the result of the voting by the ballot lists for the election of Officers for the present year. The four Members thus appointed by the Council would all retire at the next Annual General Meeting, when they would be eligible for re-election by the Members.

(The President.)

The Council for the present year will therefore be as follows:—

PRESIDENT.

JOSEPH TOMLINSON, ...	London.

PAST-PRESIDENTS.

THE RIGHT HON. LORD ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., . . .	Newcastle-on-Tyne.
SIR LOWTHIAN BELL, BART., F.R.S., .	Northallerton.
SIR FREDERICK J. BRAMWELL, BART., D.C.L., F.R.S., ...	London.
EDWARD H. CARBUTT, . . .	London.
CHARLES COCHRANE, ...	Stourbridge.
THOMAS HAWKSLEY, F.R.S., . . .	London.
JEREMIAH HEAD, ...	Middlesbrough.
JOHN RAMSBOTTOM, ...	Alderley Edge.
JOHN ROBINSON, ...	Leek.
PERCY G. B. WESTMACOTT, . . .	Newcastle-on-Tyne.

VICE-PRESIDENTS.

WILLIAM ANDERSON, D.C.L., . .	Woolwich.
SIR JAMES N. DOUGLASS, F.R.S., . .	London.
ALEXANDER B. W. KENNEDY, F.R.S., .	London.
ARTHUR PAGET, ...	Loughborough.
SIR JAMES RAMSDEN, ...	Barrow-in-Furness.
E. WINDSOR RICHARDS, . . .	Low Moor.

MEMBERS OF COUNCIL.

BENJAMIN A. DOBSON, . . .	Bolton.
SIR DOUGLAS GALTON, K.C.B., D.C.L., F.R.S., ...	London.
JOHN HOPKINSON, JUN., D.Sc., F.R.S., .	London.
SAMUEL W. JOHNSON, ...	Derby.
WILLIAM LAIRD, ...	Birkenhead.
JOHN G. MAIR-RUMLEY, . . .	London.
HENRY D. MARSHALL, ...	Gainsborough.
EDWARD B. MARTEN, ...	Stourbridge.

EDWARD P. MARTIN, ...	Dowlais.
WILLIAM H. MAW, ...	London.
T. HURRY RICHES, ...	Cardiff.
BENJAMIN WALKER, ...	Leeds.
WILLIAM H. WHITE, F.R.S., . .	London.
J. HARTLEY WICKSTEED, . . .	Leeds.
THOMAS W. WORSDELL, . . .	Gateshead.

The Discussion upon Mr. Urquhart's Paper on the Compounding of Locomotives burning Petroleum Refuse in Russia was resumed and completed; and the following Paper was read and discussed:—

On the Burning of Colonial Coal in the Locomotives of the Cape Government Railways; by Mr. MICHAEL STEPHENS, Chief Locomotive Superintendent.

At twenty minutes past Nine o'clock the Meeting was adjourned till the following evening. The attendance was 68 Members and 36 Visitors.

The ADJOURNED MEETING of the Institution was held at the Institution of Civil Engineers, London, on Friday, 31st January 1890, at Half-past Seven o'clock p.m.; JOSEPH TOMLINSON, Esq., President, in the chair.

The following Paper was read and discussed:—

On the Mechanical Appliances employed in the Manufacture and Storage of Oxygen; by Mr. KENNETH S. MURRAY, of London. Communicated through Mr. HENRY CHAPMAN, of London.

In connection with this Paper the Members were invited to visit Brin's Oxygen Works, 69 Horseferry Road, Westminster, on the three days of the Meeting and the following morning, for the purpose of witnessing the process of manufacture and inspecting the machinery employed.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at twenty minutes past Nine o'clock. The attendance was 41 Members and 34 Visitors.

ON THE COMPOUNDING OF LOCOMOTIVES BURNING PETROLEUM REFUSE IN RUSSIA.

By Mr. THOMAS URQUHART, Locomotive Superintendent, Grazi and Tsaritsin Railway, South East Russia.

In fulfilment of his promise made in a former discussion upon the Compounding of Locomotives (Proceedings 1886, page 391) the author has much pleasure in now communicating to the Institution the results of the experience he has thus far acquired in the compounding of existing petroleum-burning locomotives on the Grazi and Tsaritsin Railway in South East Russia.

Amongst the conflicting opinions entertained as to the utility of compounding in locomotives, the author, like many others, had his doubts on the subject in 1886. In order to satisfy himself on the question, he obtained the sanction of the government for altering one locomotive by way of experiment according to his own plans. The altered goods engine No. 35 was put to work on 1st September 1887; and after some modifications in the valve-gear, suggested by indicator diagrams taken in preliminary trials, it was finally completed, and the driver was allowed over a month's running to get fully acquainted with the handling in regular service. Comparative trials were then made of the compound against a non-compound with the same weight of train on the same days, the two trains being run one after the other with an hour's interval between, so as to expose them both to the same circumstances in regard to weather. It was proved without doubt that the compound burnt 22 per cent. less of the petroleum refuse used as fuel than the non-compound.

In consequence of this very favourable result, the compounding of other locomotives was at once proceeded with. At the present time (January 1890) there are already in daily use in the regular train service on this line thirteen compound goods engines with six

wheels coupled, and three compound passenger engines with four wheels coupled, all of which are doing very well indeed; and in the shops, in course of reconstruction, two passenger and four goods engines. It is intended to go on altering the rest of the locomotives to the compound plan as fast as the limited means in the railway works at Borisoglebsk will admit of this being done.

Economy of Compounding.—The fuel economy in the passenger engines the author believes cannot be less than 20 per cent. in the second or third notch, though there are not yet data enough for confirming this opinion with absolute certainty; it will be greater when the drivers manage the engines better. The mean economy in the thirteen goods engines is now found to be $18\frac{1}{2}$ per cent., which is a very good result, though less than what was got in the actual trial of the first one compounded. Including the three passenger engines therefore, the fuel economy in the compounded engines may now be safely taken at $18\frac{1}{2}$ per cent. in comparison with ordinary locomotives. Last winter 1888–89 was exceptionally severe, with from 55° to 65° Fahr. of frost; but the compounds ran equally well with the other engines, and no inconvenience on account of the great cold was experienced with them.

Dimensions of Engines.—During the progress of these alterations and of the author's observations on the working of the altered engines, several difficulties developed themselves, for which remedies had to be devised; these will no doubt interest all engineers concerned in the adoption of compound locomotives. In Figs. 1 to 4, Plates 1 to 3, are shown a side elevation on the high-pressure side, a transverse section through the smoke-box, and a sectional plan, of one of the altered six-wheel coupled 36-ton goods engines, No. 35, of which the following are the main dimensions affecting the compounding. Cylinders $18\frac{1}{2}$ ins. and $25\frac{5}{8}$ ins. diameter, and 24 ins. stroke; ratio of areas 1·000 to 1·912. Eccentrics, throw $4\frac{3}{4}$ ins.; angle of advance 20°. Slide-valves, high-pressure valve, outside lap 0·81 inch, inside clearance 0·08 inch; low-pressure valve, outside lap 0·67 inch, inside clearance *nil*.

Stephenson link-motion. Receiver, capacity 3·28 cub. ft.; surface exposed to smoke-box heat 11·52 sq. ft. Boiler pressure 9 atm. = 135 lbs. per sq. inch above atmosphere. Six wheels all coupled 4 ft. 3 ins. diameter. Adhesion weight 36 tons. Tubes, number 151, outside diameter $2\frac{1}{8}$ ins.; length between tube-plates 13 ft. $10\frac{1}{8}$ ins. Heating surface, tubes 1164 sq. ft.; fire-box 67 sq. ft.; total 1231 sq. ft. Fire-grate area 17 sq. ft. prior to burning petroleum, but no fire-grate is now used.

In Figs. 9 and 10, Plate 7, are shown sections of the two slide-valves.

The diameter of the high-pressure cylinder being $18\frac{1}{2}$ inches, and of the low-pressure $25\frac{5}{8}$ inches, the piston areas are consequently 269 and 516 square inches, or in the ratio of about one to two. The original stroke of 24 inches is retained unaltered, as is also the boiler pressure of 135 lbs. per sq. inch above the atmosphere. On first testing the engine with the original eccentrics, having a throw of $4\frac{1}{2}$ inches, and angles of advance of 30°, it was found from the indicator diagrams that very excessive compression took place in the high-pressure cylinder at early cut-off, and too early a cut-off in both cylinders. The new eccentrics now used for all the compounded locomotives have an increased throw of $4\frac{3}{4}$ inches, and angles of advance of 20°. The indicator diagrams, Figs. 29 to 32, Plates 11 and 12, taken in forward gear since these alterations were made, show an improved distribution of steam, the engine giving out ample power in the third and fourth notches for the heaviest trains up the steepest gradients on the line, of 1 in 125, Table 2; in fact, so far as the power of the engines is concerned, the compounds take their regular turns in the service, drawing the same number of trucks as the non-compounds, and keeping punctual time. The trial trains as well as the ordinary trains in summer consist of thirty loaded trucks of 16 tons each, or a total load of 480 tons exclusive of engine and tender. From these indicator diagrams 10 per cent. has been added to the mean effective pressure in each cylinder, in order to allow for the effect of the pipe connection from the cylinder to the indicator. All the engines have screw reversing-gear, enabling the driver to use any degree of expansion intermediate between the

extreme limits of mid gear and full gear; and the four and five notches mentioned on the diagrams and in the appended Tables 1 to 11 are given merely for comparison with the ordinary nomenclature when a reversing lever and a sector with four and five notches are used. For the driver's guidance a corresponding notched indicator is added, which is shown in Figs. 22 and 23, Plate 9, as fitted on the reversing gear of all the engines, so that the expansion can be ascertained in the dark by feeling the position of a projecting finger I carried upon the nut N of the reversing screw.

In Tables 5 and 6 are given the particulars of the working of the first compounded passenger engine No. 110; and in Figs. 37 to 40, Plates 15 and 16, and Fig. 49, Plate 20, are shown the corresponding indicator diagrams taken in forward gear, which are seen to be very good; the passenger engine indeed seems to work rather better than the goods.

Tractive Power.—An opinion prevails among engineers that the compounding of existing locomotives, when retaining the original boiler-pressure without augmentation and also retaining one of the original cylinders to form the high-pressure cylinder in the compound, must result in a considerable reduction in the tractive power of the compound as compared with the non-compound engine. In order to clear up this point and ascertain fully what are the relative tractive powers of compound and non-compound locomotives, a series of comparative trials were made by the author during the summer of 1889 with both passenger and goods engines. A complete trial train of equal weight was made up for each passenger engine, the gross load being equal to its full adhesion; and similarly for each goods engine. Indicator diagrams were taken at each notch, at the slow speed of only ten miles an hour. At the same time a dynamometer was placed between the tender and the train, to show the actual tractive force exerted upon the train. The trials were all made up hill, from Borisoglebsk up to Gribanovka, a distance of eleven miles, with the maximum incline of 1 in 125 for the greater part of the way, and with frequent curves of 2100 feet (32 chains) radius. In Fig. 28, Plate 10, is shown a profile of this

portion of the line. The boiler pressure was the same in all cases, namely 9 atmospheres effective or 135 lbs. per square inch above the atmosphere. The results are given in Table 7 and Figs. 41 to 50, Plates 17 to 20, for the passenger engines, compound and non-compound, both of which took trains of 344½ tons exclusive of engine; and in Table 8 and Figs. 51 to 58, Plates 21 to 23, for the goods engines, which took trains of 463 tons net.

In the compound passenger locomotive, as shown in Table 7 and Fig. 25, Plate 10, the tractive power undergoes the following diminution as compared with the non-compound, in the five successive notches of the reversing gear from the earliest cut-off to full gear :—

1st notch . .	tractive power	42	per cent.	less	in	Compound.
2nd notch . .	,, ,,	28	,,	,,	,,	
3rd notch . .	,, ,,	17	,,	,,	,,	
4th notch . .	,, ,,	7	,,	,,	,,	
5th notch (full gear)	,, ,,	5	,,	,,	,,	

In the compound goods locomotive, as shown in Table 8 and Fig. 26, Plate 10, the diminution of tractive power as compared with the non-compound is as follows for the four notches :—

1st notch . .	tractive power	27	per cent.	less	in	Compound.
2nd notch . .	,, ,,	17	,,	,,	,,	
3rd notch . .	,, ,,	10	,,	,,	,,	
4th notch (full gear)	,, ,,	5	,,	,,	,,	

Although the compounds thus show in full gear a diminution of 5 per cent., this difference from the non-compounds may for all practical purposes be neglected.

In Table 7 are given the indicated horse-power developed and also the tractive force exerted by the passenger engines, compound and non-compound, each having an adhesion weight of 24 tons. At the third notch in the compound it will be seen there is a tractive force of 4·44 tons, equal to 18·5 per cent. or 1 : 5·4 of the adhesion weight, which is quite sufficient for all practical purposes. The maximum traction in the compound, at the fifth notch or full gear, reaches 5·17 tons, equal to 21·5 per cent. or 1 : 4·6, or more than one-fifth of the adhesion weight, which the author noticed was sufficient to slip the wheels on a perfectly dry rail. The increased

tractive power shown in Table 7 over Table 6 is due both to the slower speed of only 10 miles an hour, and also to the cut-off being a little later owing to wear of the valve-gear after longer running. The object of making these later comparative trials in Tables 7 and 8 at the slower speed of 10 miles an hour, and at the full capacity of the locomotives, was to get fuller and clearer indicator diagrams than would be possible at higher speeds.

In the case of the goods locomotives, Table 8, having 36 tons adhesion weight, at the third notch in the compound a tractive power is attained of 5·56 tons, equal to 15·4 per cent. or 1:6·5; while at the fourth notch or full gear the maximum is reached of 6·42 tons, equal to 17·8 per cent. or 1:5·6 of the adhesion weight, which is quite sufficient for all practical purposes. Having fortunately been able to ascertain the foregoing facts from his own personal observations, the author will be very glad if they should be deemed sufficient to set at rest a question upon which a good deal of conjecture has hitherto existed.

In the calculation of the tractive power of the compound engines, the power of each cylinder is calculated separately by means of the formula:— tractive power = 0·57 × boiler-pressure above atm. × (cyl. diam.)^2 × stroke ÷ (2 × diam. of driving wheels). The coefficient 57 per cent., which gives the mean effective pressure on the high-pressure piston in full gear, has to be replaced by a lower figure deduced from indicator diagrams, when working more expansively; and for the low-pressure cylinder a still lower coefficient has of course to be taken.

Economy of Fuel and Repairs.—Table 9 shows the mileage, the consumption of petroleum refuse, and the cost of engine and tender repairs, in six compound and six non-compound locomotives, one of each being a passenger engine and the other five goods; the results are those of five months' working in 1889, from April to August inclusive. The saving of fuel in the compounds is seen to have been 4·55 lbs. per mile or 18·22 per cent. in the passenger engine, and a mean of 5·31 lbs. per mile or 18·96 per cent. in the five goods engines, which together made 58,580 miles; in these five engines the saving

ranged from a minimum of 14·75 to a maximum of 25 57 per cent. The saving in repairs was 49·2 per cent. in the passenger engine, and a mean of 28·8 per cent. in the goods. Naturally the whole of the saving in repairs must not be put down to the credit of the compounding alone, because all these compounded engines had just passed through the shops and undergone a complete overhaul, so that they would reasonably require less repairs in running service than the old non-compound locomotives with which they are compared. None the less is the author of opinion, as the result of his own observations thus far, that the compounds will at all times require less repairs than the non-compounds, to the extent of probably at least 25 per cent., simply from the fact that the initial strains are not so high on the bearings and other mechanism in the compounds, and the force exerted by the pistons is continued upon the crank-pins for a greater distance during each stroke than in the non-compounds. Moreover the friction of the slide-valves is much less in the compounds, because the back-pressure of about 60 lbs. per square inch under the high-pressure slide-valve tends to ease it off the face, while the low-pressure slide-valve is loaded to less than half the boiler pressure.

In Table 10, and graphically in Fig. 27, Plate 10, is shown the comparative consumption of petroleum refuse in compound and non-compound six-wheel coupled 36-ton goods engines doing equal work on the same section of line from 1st January to 31st December 1889. During the first three months of severe winter the trains were much blocked by snow-drifts, causing the traffic to be very irregular; and as the compounds require just the same quantity of fuel as the non-compounds for keeping steam up while standing, they do not show so advantageously under such conditions as in long running service. The mean consumption per engine-mile for the twelve months is seen to be 25·63 lbs. in the compounds and 31·16 lbs. in the non-compounds, showing a saving of 5·53 lbs. or 17·74 per cent. in the compounds. In conjunction with the mean saving of 18·96 per cent. shown in Table 9, the general average is roundly a saving of 18 per cent. for the whole of the twelve months' working of all the goods compounds, which together made 206,355 engine-miles.

Slide-Valves.—The results of observation show that a very small difference in lap, outside or inside, amounts to a great deal in fuel consumption. The fuel sheets for all the compounds are every month carefully scrutinised, in order to see which particular engine burns least. Out of the twelve compound goods engines now running, No. 40 working between Tsaritsin and Archeda has thus far proved the best from the commencement of its service in May 1889 to the end of October: although over the shorter period covered by Table 9 No. 43, which began running in June 1889 between Archeda and Filonoff, happens to show a little better. A longitudinal section of the two slide-valves of this engine No. 40 is shown in Figs. 11 and 12, Plate 7; and particulars of their setting in an exactly similar engine No. 42 are given in Table 11. The full travel of the valves in each case is $4\frac{1}{2}$ inches, and the exact amounts of their lap in No. 40 are as follows:—high-pressure valve, outside lap 20 mm. = 0·79 inch, inside clearance $1\frac{1}{2}$ mm. = 0·06 inch; low-pressure valve, outside lap $15\frac{1}{2}$ mm. = 0·61 inch, inside lap 2 mm. = 0·08 inch. In No. 42 however a trial is now being made of a low-pressure valve with an increased inside lap of 3 mm. = 0·12 inch, with a view to increasing the compression in the low-pressure cylinder in order to take up the extra momentum due to the greater weight of the larger piston; and this difference in the inside lap is now being watched over a lengthened period of working, for determining its importance in accomplishing the desired object. The above laps in No. 40 are an improvement upon those in No. 35 (page 48); while the further slight modifications shown in Table 11 for No. 42 are an improvement upon No. 40, and are found to give as yet the best results.

Relieved Slide-Valves.—For relieving the pressure of the slide-valves on their faces the author has adopted the plan shown in Figs. 16 to 19, Plate 8, for the high-pressure valve, placing over the back of the valve a fixed table or back-plate B, against which bear a couple of relieving rings R, let into annular grooves in the back of the valve, and pressed outwards against the plate by the steam getting under them through a small hole H made for the purpose. Any steam leaking through past the rings escapes through the tube T open to the atmosphere, whereby the valve is relieved from

the steam pressure over the area enclosed within the two rings R. For the low-pressure valve the arrangement shown in Figs. 20 and 21, Plate 8, was adopted, consisting of a piston P in a cylinder of 6 inches diameter, exposed to the steam pressure underneath and open to the atmosphere above, thus tending to lift the valve off its face by means of the connecting link L. This latter plan was tried on eight engines and did very well, but has been temporarily abandoned because it made so much noise when running without steam. In other respects however the author is so satisfied of its value that he intends to try it once more, and see if the above objection cannot be obviated. It will be seen that in neither of these plans for relieving the slide-valves are any springs used.

Sequence of Cranks.—The first four compounded engines turned out of the shops had their high-pressure crank leading and low-pressure following in forward running; and in Tables 1 and 2 are given the corresponding mean steam-pressures, and temperatures of steam, and power developed. In order to test the effect of the reverse sequence of cranks, one goods engine No. 53 was altered to have the low-pressure crank leading and the high-pressure crank following in forward running; and in Tables 3 and 4 are given the corresponding particulars for comparison with Tables 1 and 2. From the indicator diagrams taken in forward gear with the latter arrangement, shown in Figs. 33 to 36, Plates 13 and 14, it will be noticed that inconvenient and very excessive compression takes place at the first notch in the high-pressure cylinder, so much so indeed that this notch is not used; but in all the other notches a good distribution takes place. In the low-pressure cylinder a much better distribution takes place at all notches compared with engines having the high-pressure crank leading; and this engine with the low-pressure crank leading, which has only recently been put to work, seems to develop more power and to burn less fuel than the others having the high-pressure crank leading. This is the first time, so far as the author is aware, that the sequence of cranks in compound locomotives has been taken into consideration. The receiver capacity is equal to that of the high-pressure cylinder; and all the dimensions are the

same in both the above cases. Four goods engines now have the low-pressure crank leading, while all the passenger have the high-pressure leading.

The idea of making one engine by way of trial with the low-pressure crank leading in forward running originated in its being accidentally noticed that one of the other engines, compounded with the high-pressure crank leading in forward running, seemed to work better and to be more powerful, developing its full tractive force with an earlier cut-off and making steam with greater freedom, when running backwards with its train, in which case of course the low-pressure crank became the leading one. The line following generally the undulating contour of the plains, its profile has very long gradients of 1 in 125, thus demanding for long stretches at a time the full power of the engine, or say about the third notch out of four. The only objection the author now sees to the low-pressure crank leading is that it gives too much power in the large cylinder and too little in the small, thus putting the engine out of equilibrium; but this irregularity will in a great measure be obviated by having a receiver about half as large again as those now used on most of the present compounds.

Air-inlet Valve.—When the first passenger compound was put into regular train service, it was noticed that, where an ordinary non-compound ran easily down hill with the regulator closed, the compound ran very stiff, and even required the regulator opening a little: thus proving that an increased internal resistance existed in the compound locomotive, which was traced to the large area of the low-pressure piston creating a strong vacuum in the receiver. This was overcome by placing on the receiver an air-inlet valve G, Fig. 15, Plate 7, which opens inwards automatically for enabling both the pistons to draw in air when required, as is invariably the case as soon as the steam is shut off. Since the addition of this valve, the engine runs down hill with even greater ease than a non-compound locomotive. As for the objection that such a valve cools the cylinders, the author had to choose one of two inconveniences: either to keep steam on

when running down hill, or to cool the cylinders. The latter proves the more profitable method, and is accordingly adopted.

Subsequently the author has arranged for mixing part of the hot smoke-box gases with the cold air, and admitting this mixture into the cylinders at a temperature of from 120° to 180° Fahr.; this can easily be done without risk of injury to the valve-faces and piston-rings, because no solid particles from cinders or ashes exist in the smoke-box of these engines burning petroleum refuse. The plan adopted is shown in Fig. 7, Plate 5, and consists in placing upon the stand-pipe D above the high-pressure valve-chest a short perforated pipe P of $2\frac{1}{8}$ inches bore, projecting into the smoke-box, the aggregate area of the perforations being double the area of the pipe. In order that the hot gases alone may not get into the cylinders and cause damage by their great heat, a couple of air holes are made in the flap-valve F which closes the top of the stand-pipe; the joint area of the two holes is about one-quarter that of the gas pipe P, so that the air and gas get mixed in the proportion of about one to four, which as far as the author's experience goes is quite sufficient for preventing over-heating. The results are very good: the cylinders no longer get cooled as they did before; and when the regulator is opened afresh, less steam is condensed, or possibly none at all. The flap-valve F is closed by a light spring, and is at once blown wide open whenever the engine is made to work non-compound at starting.

Starting Valve.—The starting valve S on the receiver, Plates 2 and 5, for admitting boiler steam direct to the low-pressure cylinder for starting, is opened and closed by hand by the driver, and is not automatic in closing, its only merit being that it is exceedingly simple. In fact these valves were already in stock, having formerly been used for steam-brakes on the locomotives. It cannot therefore be pretended that they present the same excellent features as the special automatic starting valves which have been introduced elsewhere and have proved so efficient in working. In the author's locomotives retaining their original boilers it must be borne in mind

that his whole attention was directed simply to obtaining from old engines compounded with 8½ to 9 atmospheres pressure the nearest and cheapest approach to modern compounds having 12 atmospheres pressure. As to any possibility of a wasteful expenditure of steam through abuse of the starting valve, this is sufficiently guarded against by the drivers being paid a premium for saving fuel; they are as a rule fully alive to their own interests, and never use the starting valve more than is absolutely necessary. In Figs. 5 to 8, Plates 4 to 6, are shown a side elevation on the high-pressure side, a transverse section through the smoke-box and cylinders, and a sectional plan, of a compounded passenger engine having the hand interchanging or air-inlet valve G, in addition to the hand intercepting valve E, Fig. 15, Plate 7. On closing by hand the intercepting valve E and opening the starting valve, and also opening by hand the interchanging valve G, the three together enable the engine to continue working non-compound for any length of time, instead of for only the first stroke at starting; and the interchanging valve G serves also as an air-inlet valve for both cylinders in running down hill with the steam shut off. In Figs. 13 to 15, Plate 7, is shown the arrangement of these two valves E and G, which are indispensable for starting heavy passenger trains without jerks. The handles by which these two valves can be actuated by the driver are not locked in any position. For working compound as soon as desired after the train has been started by the non-compound working, the interchanging valve G is closed again by hand, while the intercepting valve E if not opened by hand is blown open by the exhaust steam from the high-pressure cylinder. As soon as the steam is shut off, the interchanging valve G opens automatically as an air-inlet valve for both cylinders; and the intercepting valve E, should it happen to have been closed, is also opened automatically by the pressure of the atmosphere beneath it, as soon as a vacuum is created in the receiver.

Receiver.—The first compounded passenger locomotive had a receiver capacity equal to the volume of one stroke of the high-pressure piston; but in two recently compounded the receiver has

been enlarged to 1·3 times that capacity, by the addition of the pipe A in the smoke-box, as shown in Fig. 7, Plate 5. Both these engines have the high-pressure crank leading in forward running. The enlargement of the receiver is found to be a step in the right direction, by more nearly equalising the power in the cylinders. A marked difference can be noticed in the indicator diagrams taken, as well as in the available power of the engines. There is less back-pressure in the high-pressure cylinder, and a greater quantity of steam in the receiver for charging the low-pressure cylinder; and although this steam is of slightly lower pressure, yet the diagrams from the low-pressure cylinder come out fuller. In other words, before the receiver capacity was increased it was found that the pressure in the low-pressure cylinder dropped at once on the piston starting at the beginning of its stroke; but with the enlarged receiver the pressure does not drop so fast, owing to the increased quantity of steam in the receiver.

In the compounded goods locomotive No. 28, recently put into service, with the low-pressure crank leading in forward running, the receiver has been further enlarged to 1·8 times the capacity of the high-pressure cylinder. The result is that not only is the pressure well kept up in the low-pressure cylinder from the beginning of the stroke, but also the influx of steam from the high-pressure cylinder takes place before the admission to the low-pressure cylinder is cut off at some notches of the valve-gear. Thus a pretty even pressure is obtained in the large cylinder, giving a good diagram for this cylinder, while at the same time, owing to the sequence of cranks, less resistance is offered to the exit of the steam from the high-pressure cylinder, except at the first notch or greatest expansion. From three months' performance, during September, October, and November 1889, engine No. 28 seems to work very well; and for this result three reasons may be assigned. Firstly, the hangers to the link-motion are made 5–8ths inch longer on the low-pressure side than on the high-pressure, causing a later cut-off in the low-pressure cylinder than in the high-pressure. Secondly, the blast-pipe is set 12 inches lower down in the smoke-box than in the other engines, keeping its nozzle at about the height usual in English

engines, say about 8 inches above the top row of tubes. Thirdly, the receiver as already stated is made 1·8 times the capacity of the small cylinder. Any one of these three points may have a useful effect upon the better working of the engine; and the combination of all three together has undoubtedly the effect of saving a trifle more fuel; but to which of the three it would be right to assign the benefit it is impossible at present to say from so short experience and with only one engine.

The results of the author's experience are such as to leave no doubt in his own mind that compound locomotives are the engines of the future in all countries. Plans are already in hand for compounding the eight-wheel coupled 48-ton goods locomotives;* and advantage will be taken of the alteration of these and other engines to substitute also the relieved slide-valves * above described, so as to save the extra 5 or 6 horse-power at present absorbed by the friction of the slide-valves. What is really wanted is to mature a thoroughly efficient two-cylinder compound with moving parts as light as possible and well balanced. The government railway authorities have decided in future to order all new locomotives on the compound principle. One railway has already ordered twenty-two compound eight-wheel coupled goods locomotives to work at 12 atmospheres absolute or 160 lbs. per square inch above the atmosphere. These engines are being built at the Kolomna Locomotive Works near Moscow, and have outside cylinders with the slide-valves on the top in the American fashion, and Joy's valve-gear.

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* See pages 107–111.

Equivalent Russian and English Measures.

1 sajene = 7 feet. 500 sajenes = 1 verst = 0·6629 mile.

1 pound=0·90285 lb. 40 pounds =1 pood=36·114 lbs. 62·0257 poods=1 ton.

1 pound per verst = 1·362 lb. per mile.

1 copeck = 0·24 penny. 100 copecks = 1 rouble = 24 pence.

1 copeck per pood = 14·886 pence per ton.

TABLE 1.

Mean Steam Pressures, and Temperatures of Steam,

in Six-wheel Coupled 36-ton Compounded Goods Locomotive No. 35.

High-pressure Crank leading in forward running.

See Indicator Diagrams, Figs. 29 to 32, Plates 11 and 12.

Cylinder.	Cut-off.		Steam Pressures, lbs. per square inch.					Temperatures of Steam.			
	No. of Notch.	† Percentage of Stroke.	Valve-chest.	Mean Forward.	Mean Back.	Mean* Effective. D	Mean* Effective. D×1·1	Beginning of stroke.	End of expansion.	Utilized in expansion.	Utilized in both cyls.
	No.	Per cent.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Fahr.	Fahr.	Fahr.	Fahr.
High-pressure, right hand.	1	47	132·4	92	63	29	32	356°	293°	63°	
	2	60	132·4	110	58	52	57	356°	311°	45°	
	3	72	132·4	119	55	64	70	356°	324°	32°	
	4	82	132·4	127	57	70	77	356°	333°	23°	
Low-pressure, left hand.	1	49	47·1	27	7·1	19·9	22	295°	237°	58°	119°
	2	67	51·5	34	5·7	28·3	31	298°	257°	41°	99°
	3	79	52·9	41	4·3	36·7	40	300°	273°	27°	83°
	4	86	55·9	48	2·8	45·2	50	302°	284°	18°	72°

† The point of cut-off in percentage of stroke is given as marked from the valve setting.

* The mean effective pressure in column D is the difference between the mean forward and backward pressures; in column D×1·1 it is increased by 10 per cent. to allow for the throttling effect of the indicator pipe and connections.

TABLE 2.

Power developed by Six-wheel Coupled 36-ton Compounded Goods Locomotive No. 35.

High-pressure Crank leading in forward running.

Cylinders 18½ ins. and 25⅝ ins. diameter, 24 ins. stroke. Wheels 4 ft. 3 ins. diameter.
Adhesion Weight 36 tons. Boiler Pressure 135 lbs. per square inch above atmosphere.

Grade of Expansion. No. of Notch.	Speed of train. Miles per hour.	Driving Wheels. Revolutions per minute.	Piston Speed. Feet per minute.	Indicated Horse-Power.	Tractive Power.	Ratio of Tractive Power to Adhesion Weight.
No.	Miles.	Revs.	Feet.	I. H. P.	Tons.	Per cent. Ratio.
1	20	131	524	310	2·655	7·7 = 1 to 13
2	18	117	468	452	4·192	11·9 = 1 to 8·4
3	17	100	400	476	5·543	15·8 = 1 to 6·3
4	13	87	348	475	6·195	17·8 = 1 to 5·6

TABLE 3.

Mean Steam Pressures, and Temperatures of Steam,

in Six-wheel Coupled 36-ton Compounded Goods Locomotive No. 53.

Low-pressure Crank leading in forward running.

See Indicator Diagrams, Figs. 33 to 36, Plates 13 and 14.

Cylinder.	Cut-off.		Steam Pressures, lbs. per square inch.					Temperatures of Steam.			
	No. of Notch.	† Percentage of Stroke.	Valve-chest.	Mean Forward.	Mean Back.	Mean * Effective. D	D × 1·1	Beginning of stroke.	End of expansion.	Utilized in expansion.	Utilized in both cyls.
	No.	Per cent.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Fahr.	Fahr.	Fahr.	Fahr.
High-pressure, left hand.	1	38	132·4	82	70	12	13	356°	288°	68°	
	2	54	132·4	105	73	32	35	356°	309°	47°	
	3	68	132·4	121	61	60	66	356°	322°	34°	
	4	80	132·4	131	64	67	74	356°	345°	11°	
Low-pressure, right hand.	1	38	55·88	24	11	13	14	302°	225°	77°	131°
	2	55	55·88	37	9	28	31	302°	248°	54°	108°
	3	68	55·88	43	4	39	43	302°	266°	36°	90°
	4	80	55·88	51	4	47	52	302°	286°	16°	70°

† The point of cut-off in percentage of stroke is given as marked from the valve setting.

* The mean effective pressure in column D is the difference between the mean forward and backward pressures; in column D × 1·1 it is increased by 10 per cent. to allow for the throttling effect of the indicator pipe and connections.

TABLE 4.

Power developed by Six-wheel Coupled 36-ton Compounded Goods Locomotive No. 53.

Low-pressure Crank leading in forward running.

Cylinders 18·11 and 25⅜ ins. diam.; 24 ins. stroke. Wheels 4 ft. 3 ins. diameter.
Adhesion Weight 36 tons. Boiler Pressure 135 lbs. per square inch above atmosphere.

Grade of Expansion. No. of Notch.	Speed of train. Miles per hour.	Driving Wheels. Revolutions per minute.	Piston Speed. Feet per minute.	Indicated Horse-Power.	Tractive Power.	Ratio of Tractive Power to Adhesion Weight.
No.	Miles.	Revs.	Feet.	I. H. P.	Tons.	Per cent. Ratio.
1	20	131	524	167	1·449	4·2 = 1 to 24
2	18	117	468	366	3·395	10·0 = 1 to 10
3	15	100	400	482	5·116	14·7 = 1 to 6·8
4	13	87	348	478	6·112	17·5 = 1 to 5·7

The high-pressure cylinder in this engine was worn out and had a crack in its body, and a liner was therefore put in, whereby the clear working diameter was reduced to 460 mm. = 18·11 inches; whereas the first engine compounded, No. 35, with high-pressure crank leading, had its cylinder re-bored to 470 mm. = 18·50 inches.

TABLE 5.

Mean Steam Pressures, and Temperatures of Steam, in Compounded Passenger Locomotive No. 110 with six wheels, four coupled High-pressure Crank leading in forward running.

See Indicator Diagrams, Figs. 37 to 40, Plates 15 and 16, and Fig. 49, Plate 20.

Cylinder.	Cut-off.		Steam Pressures, lbs. per square inch.					Temperatures of Steam.			
	No. of Notch.	† Percentage of Stroke.	Valve-chest.	Mean Forward.	Mean Back.	Mean* D	Effective. D × 1·1	Beginning of stroke.	End of expansion.	Utilized in expansion.	Utilized in both cyls.
	No.	Per cent.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Fahr.	Fahr.	Fahr.	Fahr.
High-pressure, right hand.	1	30	132·4	88	57	31	34	356°	286°	70°	
	2	50	132·4	110	55	55	60	356°	306°	50°	
	3	70	132·4	125	54	71	78	356°	329°	27°	
	4	80	132·4	132	53	79	87	356°	342°	14°	
	5	87	132·4	135½	52	83½	92	356°	349°	7°	
Low-pressure, left hand.	1	42	55·88	34	7·1	26·9	30	302°	243°	59°	113°
	2	60	56·61	43	4·3	38·7	43	303°	257°	46°	99°
	3	78	57·35	48	2·0	46·0	51	304°	273°	31°	83°
	4	86	57·79	53	1·0	52·0	57	305°	286°	19°	70°
	5	92	58·19	56	1·0	55·0	60½	306°	292°	14°	64°

† The point of cut-off in percentage of stroke is given as marked from the valve setting.

* The mean effective pressure in column D is the difference between the mean forward and backward pressures; in column D × 1·1 it is increased by 10 per cent. to allow for the throttling effect of the indicator pipe and connections.

TABLE 6.

Power developed by Compounded Passenger Locomotive No. 110 *with six wheels, four coupled.*

High-pressure Crank leading in forward running.

Cylinders 17¼ ins. and 25¼ ins. diameter, 22 ins. stroke. Driving Wheels 5 ft. 3 ins. diameter.
Adhesion Weight 24 tons. Boiler Pressure 135 lbs. per square inch above atmosphere.

Grade of Expansion. No. of Notch.	Speed of train. Miles per hour.	Driving Wheels. Revolutions per minute.	Piston Speed. Feet per minute.	Indicated Horse-Power.	Tractive Power.	Ratio of Tractive Power to Adhesion Weight.
No.	Miles.	Revs.	Feet.	I. H. P.	Tons.	Per cent. Ratio.
1	33	176	646	463	2·151	9·09 = 1 to 11
2	27	141	518	552	3·427	13·88 = 1 to 7·2
3	20	106	387	539	4·217	17·00 = 1 to 5·8
4	13	70	256	475	4·746	19·23 = 1 to 5·2
5	10	53	194	306	5·170	21·54 = 1 to 4·6

TABLE 7.

Power developed by Compound and Non-compound Passenger Locomotives with six wheels, four coupled; with equal trains of 344½ tons net, at equal speeds of 10 miles per hour.

Cylinders, Compound 17¼ ins. and 25¼ ins. diameter; Non-compound 17$\frac{5}{16}$ ins. diameter; 22 ins. stroke.
Driving Wheels 5 ft. 3 ins. diameter. Adhesion Weight 24 tons. Boiler Pressure 135 lbs. per square inch above atmosphere.
Revolutions 53 per minute. Piston speed 194 feet per minute. See Indicator Diagrams, Figs. 41 to 50, Plates 17 to 20.

Passenger Engine.	Cut-off.			Mean* Effective Steam-Pressure. Lbs. per square inch.		Indicated Horse-Power.	Tractive Power. See Fig. 25, Plate 10.	Ratio of Tractive Power to Adhesion Weight.	
	No. of Notch.	† Percentage of Stroke.		High-pressure cylinder.	Low-pressure cylinder.				
	No.	High.	Low.	Lbs.	Lbs.	I. H. P.	Tons.	Per cent.	Ratio.
Compound No. 110.	1	30	42	35·2	30·5	139	2·35	9·8 =	1 to 10·2
	2	50	60	60·1	44·4	215	3·63	15·1 =	1 to 6·6
	3	70	78	79·3	51·6	263	4·44	18·5 =	1 to 5·4
	4	80	86	89·5	58·2	297	5·01	20·9 =	1 to 4·8
	5	87	92	92·0	60·5	306	5·17	21·5 =	1 to 4·6
Non-compound No. 115.	1	33		87·5		241	4·07	16·9 =	1 to 5·9
	2	49		108·2		298	5·04	21·0 =	1 to 4·8
	3	57		115·0		317	5·35	22·3 =	1 to 4·5
	4	68		116·3		321	5·42	22·6 =	1 to 4·4
	5	79		117·4		324	5·47	22·8 =	1 to 4·4

† The point of cut-off in percentage of stroke is given as marked from the valve setting.

* The mean effective pressure in these columns is the difference between the mean forward and backward pressures, increased by 10 per cent. to allow for the throttling effect of the indicator pipe and connections.

TABLE 8.

Power developed by Compound and Non-compound Six-wheel Coupled 36-ton Goods Locomotives; with equal trains of 463 tons net, at equal speeds of 10 miles per hour.

Cylinders, Compound 18½ ins. and 25⅔ ins. diameter; Non-compound 18½ ins. diameter; 24 ins. stroke. Wheels 4 ft. 3 ins. diameter. Adhesion Weight 36 tons. Boiler Pressure 135 lbs. per square inch above atmosphere. Revolutions 65 per minute. Piston speed 260 feet per minute. See Indicator Diagrams, Figs. 51 to 58, Plates 21 to 23.

Goods Engine.	Cut-off.		Mean* Effective Steam-Pressure. Lbs. per square inch.		Indicated Horse-Power.	Tractive Power. See Fig. 26, Plate 10.	Ratio of Tractive Power to Adhesion Weight.
	No. of Notch.	†Percentage of Stroke.	High-pressure cylinder.	Low-pressure cylinder.			
	No.	High. Low.	Lbs.	Lbs.	I. H. P.	Tons.	Per cent. Ratio.
Compound No. 35.	1	47 49	33	23	163	2·77	7·7 = 1 to 13·0
	2	60 67	58	32	253	4·29	11·9 = 1 to 8·4
	3	72 79	73	42	325	5·56	15·4 = 1 to 6·5
	4	82 86	79	52	379	6·42	17·8 = 1 to 5·6
Non-compound No. 63.	1	38	55		223	3·79	10·5 = 1 to 9·5
	2	50	75		304	5·17	14·4 = 1 to 7·0
	3	62	89		361	6·19	17·2 = 1 to 5·8
	4	72	98		398	6·78	18·8 = 1 to 5·3

† The point of cut-off in percentage of stroke is given as marked from the valve setting.

* The mean effective pressure in these columns is the difference between the mean forward and backward pressures, increased by 10 per cent. to allow for the throttling effect of the indicator pipe and connections.

TABLE 9 (*continued on opposite page*).

Mileage, Consumption of Petroleum Refuse,
and Cost of Engine and Tender Repairs,
in Compound and Non-compound Passenger and Goods Locomotives
on the Grazi and Tsaritsin Railway,
during five summer months, April to August inclusive, in 1889.
Passenger locomotives with six wheels, four coupled.
Goods locomotives with six wheels, all coupled.

Description and No. of Locomotives.		Mileage. Average Number of Trucks in train.	Total Truck-miles.	Total Train-miles.	Total Engine-miles.	Unremunerative Engine-miles.
PASSENGER.	No.	No.				Per cent.
Compound	110	11·87	202,640	17,066	17,460	2·26
Non-compound	115	11·70	171,809	14,685	14,863	1·20
GOODS.						
Compound	35	27·39	351,698	12,847	14,195	9·50
	40	27·47	291,586	10,615	12,181	12·86
	43	27·78	145,171	5,224	6,388	18·22
	52	25·55	282,157	11,045	12,951	14·72
	58	24·43	271,974	11,132	12,865	13·47
Means and Totals		26·52	1,342,586	50,863	58,580	13·75
Non-compound	48	26·70	283,280	10,609	12,560	15·53
	34	26·81	184,463	6,880	8,363	17·73
	61	26·53	334,290	12,598	14,371	12·34
	60	30·31	238,763	7,878	10,768	26·84
	63	30·44	208,248	6,842	9,012	24·08
Means and Totals		28·16	1,249,044	44,807	55,074	19·30

The boiler pressure in all these engines, both Compound and Non-compound, was 135 lbs. per square inch above the atmosphere.

The Trucks were each about 16 tons gross load.

(*concluded from opposite page*) TABLE 9.

Mileage, Consumption of Petroleum Refuse,
and Cost of Engine and Tender Repairs,
in Compound and Non-compound Passenger and Goods Locomotives
on the Grazi and Tsaritsin Railway,
during five summer months, April to August inclusive, in 1889.
Passenger locomotives with six wheels, four coupled.
Goods locomotives with six wheels, all coupled.

Petroleum Consumption.			Cost of Repairs.		Economy of Compounds.			No. of Locomotives.
					Fuel.		Repairs.	
Total.	Per Train-mile.	Per Engine-mile.	Total.	Per Engine-mile.	Per Engine-mile.	Per cent.	Per cent.	
Tons.	Lbs.	Lbs.	£	Penny.	Lbs.			No.
159·19	20·89	20·42	17·740	0·243	**4·55**	**18·22**	**49·2**	110
165·66	25·27	24·97	29·585	0·478	...	...	...	115
145·09	25·29	22·90	22·196	0·376	4·88	17·57	48·8	35
120·59	25·44	22·17	12·356	0·243	5·04	18·52	4·0	40
60·23	25·82	21·13	4·585	0·170	7·26	25·57	24·1	43
138·33	28·06	23·93	19·977	0·369	4·14	14·75	27·7	52
130·14	26·19	23·09	31·756	0·590	5·21	18·41	39·2	58
594·38	26·16	22·64	90·870	0·350	**5·31**	**18·96**	**28·8**	
155·75	32·89	27·77	38·570	0·735	...	...	...	48
101·61	33·08	27·21	8·802	0·253	...	...	...	34
182·08	32·38	28·39	13·420	0·224	...	...	...	61
134·92	38·37	28·07	23·857	0·510	...	...	...	60
113·87	37·28	28·30	36·459	0·970	...	...	...	63
688·23	34·80	27·95	121·108	0·539	...	...	...	

In the three columns of Economy, the five Compound and five Non-compound Goods engines are compared severally according to their order of sequence:—Compound No. 35 with Non-compound No. 48, and so on to Compound No. 58 with Non-compound No. 63. The mean results show the comparison between the two groups collectively.

TABLE 10.—*Comparative Consumption of Petroleum Refuse in* 1889 *in Compound and Non-compound Six-wheel Coupled 36-ton Goods Locomotives doing equal work on the same section of the Grazi and Tsaritsin Railway.*

See Diagram, Fig. 27, Plate 10.

1889.	COMPOUNDS.						NON-COMPOUNDS.					
	Mileage.				Petroleum Consumption.		Mileage.				Petroleum Consumption.	
	Average Number of Trucks in train.	Total Train-miles.	Total Engine-miles.	Unremunerative Engine-miles.	Total.	Per Engine-mile.	Average Number of Trucks in train.	Total Train-miles.	Total Engine-miles.	Unremunerative Engine-miles.	Total.	Per Engine-mile.
	No.*			Per cent.	Tons.	Lbs.	No.*			Per cent.	Tons.	Lbs.
January	21·52	9,138	10,225	10·62	144·46	31·65	22·16	9,237	10,872	15·03	174·76	36·01
February	21·36	6,165	7,949	22·44	100·12	28·21	21·48	6,196	8,089	23·40	124·11	34·37
March	21·21	6,561	7,822	16·10	101·06	28·94	20·81	6,184	7,303	15·33	115·09	35·30
April	22·82	7,491	9,398	20·27	96·07	22·90	24·79	8,170	9,791	16·56	125·68	28·75
May	25·69	16,634	18,305	9·13	195·02	23·86	24·83	16,109	18,273	11·84	229·93	28·18
June	24·61	15,741	17,873	11·92	177·62	22·26	24·76	16,304	18,818	13·36	234·56	27·92
July	25·69	13,929	15,817	11·93	162·10	22·96	26·03	13,849	15,397	10·05	195·39	28·43
August	26·01	15,566	17,940	13·23	178·22	22·26	25·35	15,009	18,177	17·42	216·74	26·71
September	25·60	19,186	22,174	13·48	254·33	25·69	25·32	21,513	24,790	13·22	321·83	29·08
October	24·25	22,085	26,007	15·08	292·93	25·23	24·01	23,924	26,868	10·95	380·85	31·75
November	22·59	22,857	28,755	20·51	339·61	26·46	21·61	24,324	29,190	16·67	433·82	33·30
December	21·75	19,829	24,090	17·69	292·00	27·16	21·49	20,053	23,910	16·13	364·25	34·13
Means and Totals	23·59	175,182	206,355	15·20	2,333·54	25·63	23·55	180,872	211,478	15·00	2,917·01	31·16

* Trucks each 16 tons gross weight.

TABLE 11.—*Steam Distribution in Compounded Six-wheel Coupled 36-ton Goods Locomotive No. 42, with Low-pressure Crank leading in forward running, on the Grazi and Tsaritsin Railway.*

Throw of Eccentrics 4·75 inches. Angle of advance, forward and backward, 20°.
Boiler Pressure 135 lbs. per square inch above atmosphere.

See Plate 7, Figs. 11 and 12.		HIGH-PRESSURE CYLINDER, right hand. 18·50 ins. diam. × 24 ins. stroke. Outside Lap 0·79 inch. Inside Clearance 0·02 inch. Steam Ports 1·54 inch × 12·16 ins. Exhaust Port 2·72 ins. × 12·16 ins. Length of lifting links 12·99 ins. Slip of die, top 1·46 inch, bottom 1·42 inch.					LOW-PRESSURE CYLINDER, left hand. 25·59 ins. diam. × 24 ins. stroke. Outside Lap 0·57 inch. Inside Lap 0·12 inch. Steam Ports 2·16 ins. × 15·51 ins. Exhaust Port 3·94 ins. × 15·51 ins. Length of lifting links 13·05 ins. Slip of die, top 1·46 inch, bottom 1·42 inch.				
Reversing Gear.	No. of Notch.	Travel of Valve.	Lead.	Maximum Opening of Steam Ports.	Percentage of stroke.		Travel of Valve.	Lead.	Maximum Opening of Steam Ports.	Percentage of stroke.	
					Cut-off.	Release.				Cut-off.	Release.
	No.	Ins.	Inch.	Inch.	P. c.	P. c.	Ins.	Inch.	Inch.	P. c.	P. c.
Forward Gear	5	4·53	0·10	1·46	89	96	4·49	0·26	1·61	90	97
			0·10	1·50	85	95		0·26	1·57	88	96
	4	3·74	0·18	1·10	81	94	3·70	0·35	1·26	85	95
			0·18	1·10	77	91		0·35	1·26	81	93
	3	3·11	0·24	0·79	70	89	3·11	0·43	0·90	74	90
			0·24	0·79	66	86		0·43	0·90	70	89
	2	2·72	0·28	0·55	58	84	2·68	0·45	0·71	66	86
			0·28	0·55	54	79		0·45	0·71	62	84
	1	2·40	0·32	0·41	40	75	2·36	0·47	0·57	48	78
			0·30	0·41	37	70		0·47	0·57	45	74
Mid	0	2·20	0·34	0·34	17	55	2·20	0·49	0·49	26	59
			0·32	0·32	15	50		0·49	0·49	22	56
Backward Gear	1	2·36	0·32	0·39	36	72	2·36	0·47	0·55	46	76
			0·30	0·39	31	67		0·47	0·57	43	74
	2	2·64	0·28	0·51	53	81	2·64	0·45	0·71	62	86
			0·26	0·51	50	78		0·45	0·73	59	84
	3	3·03	0·24	0·71	66	88	3·03	0·41	0·90	74	90
			0·22	0·71	63	86		0·41	0·94	70	89
	4	3·58	0·18	1·06	79	93	3·58	0·35	1·10	84	94
			0·16	1·06	75	90		0·35	1·18	80	93
	5	4·33	0·08	1·38	88	96	4·33	0·24	1·53	90	97
			0·06	1·42	85	94		0·24	1·57	87	96

Discussion.

Mr. URQUHART wrote from Russia that since the preparation of the paper for the present meeting one more goods engine had now been compounded, raising the number to thirteen compounded goods engines, as stated in page 47 of the paper.

In order to reduce the friction of the piston-rods and slide-valve rods, he had now introduced metallic packing, which was giving very favourable results. One compounded engine had been running a month with this packing, which he intended to put in all his engines. He had merely adopted the plan of M. Kubler, recently illustrated in the "Revue générale des Chemins de fer" (October 1889, page 434), as then in use in 418 locomotives on the Eastern Railway of France. It was very simple, and for high pressures he believed it had a great future in marine and locomotive practice. As shown in Figs. 59 to 62, Plate 24, it consisted of a series of rings of triangular section, forming alternate solid and hollow cones, each pair of which tightened themselves against the rod and against the stuffing-box. The rings were made of white metal, consisting of 80 per cent. lead, 8 per cent. antimony, and 12 per cent. tin.

Mr. WILLIAM SCHÖNHEYDER was sure the Members all entertained a high opinion of the author, who had already given them two previous papers on the subject of his petroleum-burning locomotives. They knew too the high estimation in which he was held in Russia, being indeed almost the only Englishman who had not been driven out of that country. It seemed therefore a little surprising to meet with the statement in page 49 of the present paper that from the indicator diagrams exhibited 10 per cent. had been added to the mean pressure in each cylinder, in order to allow for the effect of the pipe connection from the cylinder to the indicator. The next time the author was kind enough to send the results of his experience, he hoped he would see his way to fitting proper indicator pipes, which should enable diagrams to be obtained that were perfectly accurate and reliable. If the pipes were not as straight and direct as they ought to be, it was possible that 10 per cent. might be too little to

add; in some cases in which the pipes had been too long and with too many bends, as much as 30 per cent. of error had been found.

The relieving rings on the back of the high-pressure slide-valves, shown in Figs. 16 to 19, Plate 8, seemed to be plain parallel cylindrical rings; and the author had stated that for the purpose of holding them up against the back-plate B he did not use springs, but admitted steam under the rings through a small hole H. That did not appear to himself to be a safe and reliable plan, because, especially at starting, as much steam pressure might get on the top of the rings as could be got underneath them through the small inlet hole H. The proper way of shaping the rings he considered would be to flange them outwards more or less at their inner face, making them more of an L section, so that there should be a considerable excess of pressure underneath as compared with what there was on the top of them. Even if there were only a slight leakage of steam between the outer face of the rings and the back-plate, he did not understand how they could be kept tight, or be certain of being up to their work at starting, when first turning steam on. It was true that the drawings showed a small tube T open to the atmosphere, for the escape of any steam leaking through past the rings; but he should prefer a much larger hole, which could not be stopped up, so that if anything went wrong with the relief ring it might be corrected at once and not allowed to go on.

The present paper was certainly a most valuable one, containing a great deal of very useful information, and showing as it did that the mean economy of 18 per cent. was obtained by merely compounding.

Mr. W. WORBY BEAUMONT had also noted the 10 per cent. which appeared from page 49 to have been added quite arbitrarily to the mean pressure from the indicator diagrams; and he thought it very undesirable for indicator diagrams to be so taken that such an uncertain result should be obtained.

The new eccentrics now used for all the author's compounded locomotives were stated in page 49 to have an increased throw of $4\frac{3}{4}$ inches. As the throw had previously been $4\frac{1}{2}$ inches, an increase

(Mr. W. Worby Beaumont.)

of $4\frac{3}{4}$ inches would make $9\frac{1}{4}$ inches; and he presumed therefore the meaning was that the throw had been increased to $4\frac{3}{4}$ inches.

The effect of enlarging the capacity of the receiver between the high and the low-pressure cylinder had been described in page 59; and without further information than was there furnished, the inference seemed to himself to be that, by going on increasing the receiver capacity, more and more work would be got out of the steam coming from the high-pressure cylinder. But there was of course no reason to suppose that, when the receiver capacity had been enlarged, a greater quantity of steam had come from the high-pressure cylinder: so that, unless other alterations had also been made, such as increasing the bore of the steam passages in the low-pressure cylinder, it was difficult to understand why so much better results should be got from the low-pressure cylinder by simply increasing the receiver capacity, although the increase had been from so small a volume as 1·0 up to only 1·3 times the capacity of the high-pressure cylinder. In page 56 the author seemed to speak in general terms of increasing the amount of receiver space to about half as large again. It might be that satisfactory results would be arrived at by proceeding in that tentative way; and it would be interesting to know what the results were, when so arrived at. At the same time he should like to know something a little more definite as to the reasons for increasing the receiver space in that way.

In reference to the increased economy obtained from the compounded engines, it did not seem quite clear to himself that the engines compared had always worked under the same conditions. He should like to know whether the experiments had been extended over a sufficient length of time for enabling any errors or discrepancies in the experiments, or in the runs and the work done by the engines, to be practically eliminated.

With regard to the plan of relieving the pressure on the back of the low-pressure slide-valve (page 55) by means of a piston and connecting link, he had in his possession designs that he had made for a similar arrangement when with Messrs. Ransomes nearly twenty years ago.

The present paper he thought was a very valuable one, giving definite facts and figures; and, with the exception of the one or two

points that he had mentioned, he regarded it as an important addition to the literature of the development of the compound locomotive engine.

Mr. W. STEELE TOMKINS considered the Institution was indebted to Mr. Urquhart for his energy in sending facts to the Members—an energy that might well be copied by other engineers elsewhere. One point to which he wished to draw attention was that, while the comparison in the paper was made to show the efficiency of the compounded engines and their economy, it appeared from page 51 that the tractive power developed after the compounding ranged from 5 to 35 per cent. less than that of the non-compound engines. On the other hand, economy of fuel was claimed for compounding to the extent of about 18 per cent.; so that, if one was put against the other, there would not be much net gain. But this of course did not cover the whole of the arguments for and against compounding. Another point was that the economy in repairs wanted establishing, because, as explained in page 53 of the paper, the comparison was at present made between old non-compound engines, and comparatively new compounded ones; and naturally the latter engines, having worked only five months when Table 9 was compiled, had not undergone repairs of boilers, tubes, fire-boxes, and other parts, which would largely increase the item of repairs. In the indicator diagrams exhibited, there was one point that he did not understand. Since the quantity of steam which could enter the low-pressure cylinder was a fixed amount, being the quantity discharged from the high-pressure cylinder, he did not see how it was that, the moment the steam was admitted from the receiver into the low-pressure cylinder, the pressure did not immediately fall and continue to fall. Instead of this, some of the low-pressure diagrams showed nearly a horizontal straight line during the admission. These were points on which he thought some further information was required. The suspended slide-valve shown in Figs. 20 and 21, Plate 8, for the low-pressure cylinder had been tried, if he remembered rightly, on the Great Western Railway many years ago, and had been discarded. Mr. Urquhart he hoped might be encouraged to continue

(Mr. W. Steele Tomkins.)
his experiments with compounding, in the direction possibly of using higher pressures and with cylinders of altered dimensions.

Mr. JEREMIAH HEAD, Past-President, mentioned that he had himself tried the suspended slide-valve shown in Figs. 20 and 21, Plate 8, about twenty-five years ago, on two large rolling-mill engines, and while it was new it had proved very efficient indeed in taking the friction off the slide faces. But one morning he found that one of the engines had stopped, and that the piston which balanced the valve had blown out right through the roof, and come down some distance off. On examination he found that for want of lubrication of the pin joint at the inner end of the connecting link the pin had actually got cut in two, and had thereby liberated the piston, so that it had been blown out at the top of the cylinder. He had accordingly reverted to an ordinary valve-chest cover, and the valve had been worked with the full pressure of the steam on it unrelieved thereafter.

Mr. JOHN A. F. ASPINALL pointed out that one great advantage which the author enjoyed in compounding his locomotives was that he was using liquid fuel as against coal; because with the use of liquid fuel a much larger blast-pipe could be employed, and it was not requisite to contract the area of the blast-pipe in order to urge the fire, and any back pressure that would otherwise exist in the low-pressure cylinder was thus got rid of. Recently he had himself been trying some experiments with liquid fuel for ordinary locomotive work on the Lancashire and Yorkshire Railway, and it seemed to answer uncommonly well. The only difficulty at present was the price. If liquid fuel instead of coal could be got for locomotives generally at a reasonable price, he had no doubt that it would be used extensively. In this respect the author had opportunities in Russia which were not likely to be met with in England at present.

The use of metallic packings had increased a great deal; and if they were properly made and well fitted at first, they might be expected to run a long time. A number of metallic packings had been introduced; but some of them had failed, mainly because they were too complicated. The one shown in Figs. 59 to 62, Plate 24, he

had no doubt would do thoroughly well, if it was well fitted to start with. He had one or two engines running with a packing of a similar character; they had been fitted last year, and the packing had never been touched since then as far as he knew, having now been running about twelve months.

It seemed to have been pretty generally understood hitherto that a starting valve, something like that shown in Fig. 15, Plate 7—but automatic, which that was not—for admitting the high-pressure steam into the low-pressure cylinder, was an absolute necessity in engines of the two-cylinder class, for convenience in starting. In Mr. Worsdell's compound engines, as was well known, such an automatic valve was used, and in fact it constituted one of the main features of his plan (Proceedings 1889, page 87). From the present paper however the author appeared to be able to do without any such automatic arrangement; and he should be glad therefore to hear something more about how the plan of controlling the starting valve by hand was found to answer in regular working.

There was of course one great advantage about the locomotives shown in the drawings, namely that they had outside cylinders. That kind of engine was one which was easily altered for compounding, because it was not confined within the narrow width of only 4 feet 2 inches in which to get both the large and the small cylinder. Where there was only the width of 4 feet 2 inches, it became a difficult matter to get reasonably large cylinders in between the frames, without cutting the frames themselves. He did not know the exact dimensions of Mr. Worsdell's engines on the North Eastern Railway, but he believed the width between the frames was something under 4 feet 2 inches; and in that case he understood it had been necessary to get over the difficulty by increasing the depth of the frames considerably. That was an objection in the way of compounding inside-cylinder engines, because it precluded taking an old engine and merely putting a new pair of compound cylinders into it, and thereby turning it out again so as to do sufficient work, such as it had been doing before it was compounded; and in the case of a railway having a large number of engines, this was a matter requiring careful consideration.

The PRESIDENT asked where Mr. Aspinall got the liquid fuel which he had experimented with, and of what description it was.

Mr. ASPINALL replied that the experiments he had been trying were of a limited character. The fuel he had been using was simply tar from gas-works. The arrangement for burning it was practically that of Mr. Holden on the Great Eastern Railway (Proceedings 1889, page 71); and he had put it upon a shunting engine which was working systematically in hauling coal trains. So far as that trial had enabled him to judge, it seemed to do very well indeed: so much so that he was thinking of trying it upon an engine doing regular main-line work, if the liquid fuel could be obtained at a price which would enable it to compare favourably with coal. It had not been used in train work yet; but it had been working sufficiently long to show that there was no difficulty in maintaining the pressure of steam, without using any coal whatever. It was of course an advantage to be able still to use coal, should the supply of oil fall short at some country station where there was no opportunity of replenishing it. In burning liquid fuel only, all that was necessary was to take care that the fire-bars were thoroughly covered up, so as to prevent any air from coming in through them.

Mr. R. HERBERT LAPAGE thought great credit was due to the author for what he had done in compounding his locomotives. He appeared to have converted ordinary locomotives into compound; and with the limited means at his command he had made a very successful compound engine. The intercepting valve shown in Fig. 15, Plate 7, he thought required too much handling, and if it were not made automatic, the driver had an opportunity of using live steam at any time in the low-pressure cylinder: in which case the steam used was not properly expanded, and naturally the low-pressure piston and working parts would have to be made stronger, and the engine balanced accordingly. There would always be a great temptation to a driver to avail himself of the boiler steam in the larger cylinder, which might easily result in running short of fuel and water. The object of an automatic intercepting valve was to prevent the driver from

using live steam in the larger cylinder when not necessary; and also to prevent the back pressure from becoming equal to the forward pressure in the high-pressure cylinder. The compound thus arranged required only the regulator and reversing handle, the same as in the ordinary engine. He was glad to learn that the author found it advantageous to increase the size of the receiver; as long as it was not made too large, there was no doubt an advantage in increasing its size. The air-inlet valve on the receiver (page 56) had the desired effect of destroying the vacuum in the receiver, and allowing the compound engine to run more steadily or smoothly down an incline. With regard to the three points mentioned in page 59 as combining to bring about the saving of a trifle more fuel, he imagined that the saving was really due to the differential valve-gear, of which he had himself made use for many years, and had certainly found it a great advantage. In a compound engine great care had to be taken that the valve-gear was suitably proportioned for both cylinders to develop equal power; otherwise his own experience was that compounding would be attended with poor results. It was interesting to see that the author had kept the same boiler-pressure in compounding, thus proving that it was not necessary to increase the pressure for the compound engine. Of course more advantage was gained by increasing the pressure, because ordinary engines could not utilize quite so high a pressure as could be employed in the compound. It was said that the steam could be expanded better in the compound engine; and by taking the same boiler-pressure the author had shown that this was the case, and that the expansion was only a matter of cylinder capacity. It was not really necessary to have a higher pressure in the compound, but merely to increase the cylinder capacity to the extent necessary for properly expanding the steam. For overcoming the difficulty of not having enough room for the cylinders between the frames, or where outside cylinders could not pass existing platforms at stations, he had just been designing a compound engine having the usual single low-pressure cylinder replaced by two low-pressure cylinders, cast in one casting one above the other, the pair of piston-rods being coupled to the same cross-head. Everything else was exactly the same; a single

(Mr. R. Herbert Lapage.)

slide-valve served for the pair of low-pressure cylinders, being placed either at the bottom or at the side or on the top; and it was worked by the same valve-gear that was used for a single high-pressure cylinder. He was glad to see that compounding seemed to be progressing in every direction; there were now between 500 and 600 compound locomotives running in different parts of the world on the Worsdell von Borries and Lapage system. Since the reading of his own paper on this subject a year ago (Proceedings 1889, page 85), the compound engines therein referred to as having then been sent abroad had been reported to have given exactly the same results after about a couple of months' trial, namely a saving of about 20 per cent. of fuel. He believed there was no doubt that a properly designed compound engine did give about that amount of saving.

The PRESIDENT enquired what was the highest pressure used, or the boiler pressure, in the compound engines which showed a saving of 20 per cent. in fuel.

Mr. LAPAGE replied that the boiler pressure was about 175 lbs. per square inch above the atmosphere. But he thought the higher pressure did not matter as regarded the economy to be obtained from compounding, which depended upon the proper proportion of the cylinders: the compound engine might be worked at 120 lbs. pressure, but the size of the cylinders must then be increased. On this account it was that he should prefer to work the compound at 200 lbs. pressure, so as to avoid such large cylinders, while also properly utilizing a high pressure.

The PRESIDENT considered there would be an objection to working a compound locomotive at so low a boiler pressure as only 120 lbs.; because, if the pressure ever happened to go down a little, it would certainly occasion a greater inequality of work in the compound engine than in an ordinary two-cylinder non-compound engine.

Mr. LAPAGE thought there was but little difference in that respect between the compound and the non-compound. There was

no difficulty at all in keeping up steam with the compounds; in fact they appeared to steam better than the others.

Mr. BENJAMIN WALKER, Member of Council, said the early part of his life had been devoted to making locomotives without compounding, but the latter part to making stationary engines with compounding; and the puzzle to himself was this. The non-compound locomotive was adhered to by Mr. Johnson on the Midland Railway, and by Mr. Stirling on the Great Northern; while the compound had been adopted by Mr. Webb on the North Western, and by Mr. Worsdell on the North Eastern. For either plan the reasons set forth seemed convincing, until those on the other side were advanced. The result was that he had been reduced to falling back upon his own common sense. His first experience with a compound engine had been more than thirty years ago. In that instance there had not been any alteration in the boiler pressure, nor in anything else, except putting in a low-pressure cylinder to make the engine work compound, the larger cylinder being of the proper size to suit the boiler pressure employed, which was only 60 lbs. per square inch above the atmosphere. The saving of coal by compounding was proved beyond dispute: there was much less coal to be carted into the coal-hole every week; and at the end of the year there had been so much less coal used, while the mill had been driven just the same. It did not want any reasoning then to convince him that the saving was really effected, and that it arose from the compounding. From his own experience therefore he said unhesitatingly that the compound system was the right one with such high pressures as 150 or 200 lbs.; for with such high pressures he considered it was impracticable to get all the power out of the steam in so short a stroke as only 24 to 28 inches in a single cylinder; in his opinion the only possible way of getting all the good out of the steam most advantageously in so short a stroke was by expanding it successively in two cylinders. He believed both Mr. Webb and Mr. Worsdell had satisfied themselves that they were doing better with their compound engines than with the non-compounds; but at the same time he himself thought they had clung too much to the old inside-cylinder principle, endeavouring to make

(Mr. Benjamin Walker.)
everything come in within the width between the frames. If some of the existing notions about the arrangement of locomotives and their frames could be discarded, and an entirely new design could be worked out in a proper manner, he was sure it would be found that the compound would work more economically than the non-compound. To the development of some such new design before long he confidently looked forwards, in the anticipation that it would be as simple as an ordinary engine, while a great deal more economical.

Captain FAIRHOLME thought it might interest the meeting to have a few data which had been furnished to him by Mr. Klien, locomotive director of the Royal Saxon State Railways, as to their experience in compounding, which had been carried out to a great extent on those lines. They had commenced in 1885 with one goods engine, and in 1886 with one passenger engine; and the number had gradually increased, until last autumn they had twenty compound engines in constant traffic, and twenty-eight more compounding or ordered to be compounded, thirty-four of the entire forty-eight being goods engines. The average saving of fuel in 1888 with seven express compound engines had been 19 per cent., and with eleven goods engines 20 per cent., being roughly about £50 a year per engine. The relative areas of the two cylinders had at first been made as 1 to 2; but it had since been found that 1 to 2·4 gave a better result, because with this ratio all grades of expansion could be used, as well for running backwards as forwards. A great improvement which was at present being introduced in the compound locomotives was the new Lindner starting gear, which was connected with the ordinary reversing gear in such a way that the engine-driver when using the reversing gear was thereby necessarily actuating also this starting gear. This gear did away with the necessity of any automatic starting valve, because its lever was connected directly with the head of the lever of the reversing gear; and on starting the engine steam was admitted to both sides of the high-pressure piston, whereby the resistance against that piston was entirely relieved in all positions when it was not being driven directly by the fresh steam, and sufficient steam was admitted to the low-pressure cylinder to start the engine.

The PRESIDENT enquired how the compound engine was worked with one reversing lever, so as to admit boiler steam to the low-pressure cylinder at starting, and not to continue so admitting it afterwards in the regular working.

Captain FAIRHOLME explained that there were two very small ports cut in the inner flanges of the slide-valve itself, and through one or other of these the receiver steam was always admitted to the driving face of the high-pressure piston during every portion of the stroke during which the boiler steam was not being admitted to that face direct from the high-pressure steam-chest.

In the absence of this provision, the boiler steam admitted to the receiver—for starting by means of the low-pressure cylinder whenever the high-pressure cylinder has both its steam-ports covered by the slide-valve or whenever the high-pressure crank is at either of its dead points—would have access to the exhaust side only of the high-pressure piston, and would therefore exert a resistance in this cylinder opposing the starting force in the low-pressure cylinder. By the Lindner gear the boiler steam admitted to the receiver for starting has access thence to both sides of the high-pressure piston, against which therefore no effective back-pressure is exerted during the time that there is also no effective driving pressure upon it. The arrangement is shown in Figs. 63 to 67, Plate 24. A starting cock C, for admitting the boiler steam to the receiver R, has two ways cut through its plug at right angles to each other, Fig. 64; and the arm A on the plug is connected by the link L with the arm M of the reversing weigh-shaft, so that the extreme motion of the reversing gear rotates the plug of the starting cock through exactly a right angle, in order that one or other of the ways through the cock may always be open in full forward and full backward gear. The boiler steam is brought to the starting cock by the small pipe P, either from the regulator, or from any nearer point in the steam-pipe leading to the high-pressure cylinder. The slide-valve of the high-pressure cylinder, Figs. 66 and 67, has two small ports *a a* cut through its flange on the exhaust side, in such a position that the length of the face between either port *a* and the adjacent outside edge of the valve is exactly

(Captain Fairholme.)

equal to the length of the steam port in the cylinder face. Thus the boiler steam in the valve-chest can never escape into the exhaust through either of the small ports *a a*; but the receiver steam in the exhaust port can always pass through one or other of the small ports *a a* to the driving face of the high-pressure piston, whenever that face is not receiving boiler steam direct from the high-pressure steam-chest in the ordinary way. By this means the resistance is neutralised which otherwise would exist if the receiver steam acted only on the exhaust side of the high-pressure piston, when the high-pressure crank might be standing at an angle of even as much as 50° from the nearest dead point.

In order to start the engine, the reversing lever is placed as usual in full forward or full backward gear, whereby simultaneously the starting cock is opened for admitting the boiler steam from the small pipe P to the receiver R, and thence to the steam-chest of the low-pressure cylinder, as well as to both sides of the high-pressure piston whensoever the high-pressure slide-valve covers both of the steam ports of that cylinder. The high-pressure piston is thus relieved from all opposing resistance in every position in which it is not being driven forwards directly by the boiler steam from its own valve-chest. As soon as the engine has been started and is well in motion, the reversing lever is set back exactly as in an ordinary locomotive, so as to admit less steam; and this movement simultaneously closes the starting cock C, thereby shutting off the small supply of boiler steam to the receiver, and causing the engine to work purely on the compound plan. The effect of the two small ports *a a* in the high-pressure valve cannot be detected in the indicator diagram, even when taken at the slowest speed: so that practically it may be said that they do not act whilst the engine is running, their action being limited to the moment of starting. This plan has answered well, owing to its remarkable simplicity, easy control, thorough reliability, and trifling cost for maintenance, as well as from the fact that the driver has nothing different to do on the compound locomotive, because the Lindner gear requires no special handle, nor have the ordinary handles to be used in any different manner.

Mr. EDWARD B. MARTEN, Member of Council, asked why the arrangement shown in Figs. 20 and 21, Plate 8, for relieving the pressure on the back of the low-pressure slide-valve, had been given up because of the noise; and what was the nature and cause of the noise.

The PRESIDENT imagined that the noise occurred only when running without steam, under which condition the valve would be caused to flap off and on its face by the inertia of the piston and connecting link.

Mr. G. S. YOUNG called attention to the author's remarks about equalising the power in the two cylinders, for which object the enlargement of the receiver was spoken of in page 59 as a step in the right direction, and in page 56 it was said to be a disadvantage to have the low-pressure crank leading. In the construction of compound engines however, the power in the two cylinders might easily be equalised by varying the cut-off at the low-pressure slide-valve. If the low-pressure cylinder was developing too much power, then by cutting off later in that cylinder the pressure in the steam receiver was reduced, the power in the high-pressure cylinder was increased, and the power in the low-pressure cylinder was diminished. Similarly if on the other hand the low-pressure cylinder was developing too little power, it could be increased by cutting off earlier with the low-pressure valve. This sounded like an anomaly, but it was a fact, and was due to the reaction of the low-pressure valve upon the high-pressure cylinder. By increasing the pressure in the receiver the low-pressure diagram was increased in area, and this was accomplished by cutting off earlier with the low-pressure valve. Looking at the indicator diagram for the fourth notch in Fig. 32, Plate 12, it would be seen that there was a hump in the middle of the low-pressure diagram, which simply meant that the low-pressure cylinder port was wide open to the receiver at the time when the exhaust from the high-pressure cylinder took place. On account of the receiver being too small, there was a varying pressure in the receiver, and of course a varying pressure also in the low-pressure cylinder which was open to the receiver. If that receiver, instead of being made only equal to the capacity of the high-pressure cylinder,

(Mr. G. S. Young.)

had been made three times as large, the diagram for the fourth notch in Fig. 32 would have been more nearly like that for the fourth notch in Fig. 36, Plate 14. Having himself made many compound marine engines with the receiver three times the capacity of the high-pressure cylinder, he had invariably found that the pressure in the low-pressure cylinder followed the stroke just in the same way as if the cylinder were receiving steam from a boiler, and it was without the fluctuations shown for the fourth notch in Fig. 32. That particular diagram indeed was a most imperfect one, because it could not be considered the proper time to admit a fresh supply of steam into a cylinder after the piston had travelled through nearly half its stroke. The proper time for admitting steam was at the beginning of the stroke; and the only way to minimise the evil of the late cut-off, which appeared to be necessary in the low-pressure cylinder of the compound locomotives described in the paper, was by having a very large receiver. In ordinary compound marine engines the steam would be cut off in the low-pressure cylinder at probably about 60 per cent. of the stroke, before the greater part of the steam was exhausted from the high-pressure cylinder: so that the hump in the middle of the low-pressure diagram was avoided. But wherever it became necessary to increase the power of the engine without increasing the revolutions, by cutting off later in both cylinders with a small receiver, there was always a hump in the middle of the low-pressure diagram, like that shown. While therefore he considered the author was correct in speaking of the enlargement of the receiver capacity as a step in the right direction, he thought it was entirely incorrect to assign as a reason that the increase was necessary for the purpose of equalising the power in the cylinders; and further, while the choice of the high-pressure or the low-pressure crank leading was germane to the question of equalising the combined twisting moments, it need have nothing to do with equalising the power in the cylinders. This object might be accomplished by altering the cut-off of the low-pressure valve.

Mr. WILLIAM GALLOWAY mentioned that he had had a small experimental compound winding engine made for the purpose of

testing how far compound engines could be adopted for winding in colliery shafts. In that case it was necessary at starting, the average boiler-pressure being about 135 lbs. per square inch, to admit steam at about 35 lbs. pressure to the low-pressure cylinder during the full length of the stroke, as the load had to be lifted from various depths at different times; and in order to supply steam of this pressure to the low-pressure cylinder, a supplementary pipe was laid from the steam-pipe of the high-pressure cylinder, from a point between the main stop-valve and the engine, to the intermediate pipe between the two cylinders. Upon the supplementary pipe were placed a small stop-valve and a reducing valve, the latter being nearer to the low-pressure cylinder than the small stop-valve. The amount of steam passing through the reducing valve was exceedingly small, and did not seem to affect the working of the engine at all after it had started. In addition to the small stop-valve and the reducing valve upon the supplementary pipe, a pressure-gauge was also fixed upon the intermediate pipe, for the purpose of observing the pressure of steam in it, and thus affording the means of regulating the reducing valve. The object of the reducing valve was simply to prevent the steam which passed into the intermediate pipe from attaining a greater pressure than was required for starting the engine when raising a load with the crank of the high-pressure cylinder at one of its dead points. The small stop-valve was kept nearly shut at all times, so as to prevent the reducing valve from vibrating when the engine was running. The system worked admirably, and the engine could be started at any point; it was in use for raising water night and day during various periods of several months at a time, starting and stopping on the average once per minute. At the present moment he was about to erect a large tandem compound winding engine of about 900 horse-power, and in this case also a reducing valve would be interposed between the high-pressure and the low-pressure cylinders, with the object above explained.

The PRESIDENT was sure the Members would all feel very much obliged to Mr. Urquhart for having so unreservedly communicated to the Institution all the difficulties he had gone through and all the

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experience he had acquired. The difficulties had no doubt been many; and in a country like his, where he had no coal and had to buy it at a heavy expense, he had done a very wise thing in using liquid fuel. In his previous papers he had given the results of burning in his locomotives petroleum refuse, as he had called it, which was simply petroleum in its crude state with all its impurities, after the best portion had been separated for other uses; and he had shown a saving in weight of something like 45 per cent. over coal. It was well known that in carrying coal from England to any internal place in Russia, or even to any sea-port there, it got a good deal of handling, and when it arrived it was not much like the coal as it had left England. It was like coal that had been stacked; and it had suffered at least from 5 to 10 per cent. depreciation in value. If therefore Mr. Urquhart could buy petroleum refuse at the price he had mentioned in his former papers, it was clearly to his benefit to use the native material found on the spot, if he could succeed in working his engines with it at all.

In now dealing with the further subject of compounding these same locomotives burning petroleum refuse in Russia, a totally different question was introduced from that of which the author had treated in his previous papers. He now claimed to have effected a further saving of 20 per cent. in fuel by compounding, which would bring the total saving up to 55 per cent. in the compound locomotives burning petroleum refuse, as compared with the ordinary locomotives burning coal. Having heard Mr. Walker's experience on the subject of compounding (page 83), he could perfectly understand how there must of necessity be a large gain in taking more heat out of the steam before it was dissipated. But the working of locomotives was a totally different thing from the working of mill engines or marine engines. When an Atlantic steamboat left Liverpool, the captain gave the order "full speed ahead," and did not alter it until he ordered "slow speed" on arriving at Sandy Hook, off New York. Such a voyage presented the proper conditions for working compound engines. The engineer had nothing to do but to maintain steam in the boilers at one uniform pressure throughout; and if the cylinders were properly proportioned, the results should be the perfection of results. It was the

same in the case of a mill engine driving a certain number of spindles or a certain number of looms; or an engine pumping water continuously under a constant head was perhaps the best example. There was a constant quantity of work to do at every stroke; and by maintaining the steam pressure regular in the boiler without altering the throttle-valve, and by also maintaining the vacuum regular if there was a vacuum, it was possible to get a uniform indicator diagram from hour to hour and from day to day. Up to this point he fully appreciated the practical advantages of compound or triple-expansion engines. But on almost every English railway, if a locomotive engine ran from any one station to any other and back, nearly 50 per cent. of the work was done down hill; and if the down-hill work was done practically with no steam, it could not matter whether the engine was compounded or not compounded. This was one of the points which seemed to him to be not duly regarded by those who advocated the compounding of locomotive engines. Assuming that there was the same driver and the same engine doing the same work, the greatest result that he could see in compounding, even if the low-pressure cylinder were four times the capacity of the high-pressure, was only about 15 per cent. saving of fuel theoretically. Now 15 per cent. was only a little over one-seventh of $2\frac{1}{2}d.$ per mile, which was the average cost for coal. If there were, as in Mr. Webb's compound, three engines to maintain instead of two, and if the repairs in a two-cylinder engine came also to $2\frac{1}{2}d.$ per mile, certainly one-third of that 15 per cent. must be applied to the increased wear and tear of the machinery, thereby reducing the saving to 10 per cent. Therefore the saving could not by any possibility amount to so much as the 20 per cent. which had been spoken of. Whatever the saving in fuel might be, every expense that had to be incurred in the compound engine, beyond what was spent on the engine before compounding, must be so much taken out of the percentage of saving. If there were three cylinders instead of two, there were three engines to maintain and to oil, and the entire engine was heavier than before, causing more wear and tear. It was therefore necessary to balance one thing against another. He was certainly much inclined to think that the 20 per cent. spoken of as the saving

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in compounding was not really 20 per cent. in fuel, but only 15 per cent. Now if the fuel was taken at one quarter of the total running expense, as it certainly might be, the percentage of saving was reduced from 15 per cent. to only $3\frac{3}{4}$ per cent. Therefore the saving of fuel was not all that it appeared by itself to be.

With regard to running, if there were larger cylinders there must be more wear and tear; and therefore when the author said that his compounded engines had cost so much less for repairs than the others, he had rightly explained the statement by adding that the engines which he had compounded had just come out of the shops, and were thus in a better condition than the others.

As to getting the 20 per cent. of saving in fuel, it must be remembered that there were the drivers also to be considered. Having himself been working locomotives for forty years, he had had a weekly or fortnightly sheet of the working of all the engines on every link of the railway, with the names of the men working them. As an example, on the Metropolitan Railway he had allowed 32 lbs. of coal per train-mile to every driver working; and if he saved 1 lb. per train-mile throughout a month he was paid 4*s.* and his fireman 2*s.*, making in all 6*s.* premium. This was assuming a run of between 3,000 and 4,000 miles per month; because the premium was of course regulated by the mileage. There were sixteen or seventeen drivers on a link, and he had found that some of them never received any premium at all; on the contrary they always exceeded the 32 lbs. per mile, and in some cases they reached 37 to 40 lbs. a mile. Other drivers ran the self-same class of engine with the self-same trains on only 26 lbs. per mile, showing a wide difference. To satisfy himself that it was not the fault of the engines, he had reversed the men and the engines, and the result had been precisely the same. The driver who burned highest with his own engine burned also most with the engine with which the other driver had burned only 26 lbs. A liberal discount ought therefore to be made from all statements as to the large amount of saving effected, because the same drivers did not work the compound engines who worked the non-compound; and if the drivers were reversed, probably the reverse result would follow, and the compounds might be found to have burned more than the

others. He once remarked that Mr. Webb of course did not put any but his best drivers on his compound engines; neither should he do so himself under similar circumstances. Still it was necessary for engineers to look at this question from all the different points of view; and therefore he did not deprecate the compounding of locomotive engines, although he did deprecate the suggestion that they were saving so much from a cause which he considered was not the real cause, because the driver had as much to do with it as the engine. A much earlier example of the difference between the drivers was furnished by some experiments which had been made in 1847 on the South Western Railway for Mr. John Gooch, with eight drivers working in a link. A new engine had been turned out of the shop, and was set to work the self-same train every day. Eight drivers ran her in this way: No. 1 driver took her for three days and left her; No. 2 driver washed her out on the following day and ran her for three days; No. 3 driver did the same, until the eight drivers had run the engine twenty-four days. She was then washed out by the last driver No. 8, who ran her another three days; and then the other seven drivers worked twenty-one days, backwards to No. 1. There was another man on the engine, who measured the water and weighed the coal and the ashes and the clinker. The result was 15·45 per cent. difference between the best driver and the worst, working the identical engine and the identical train: or the lowest for his six days was 19·6 lbs. per mile, and the highest 22·63 lbs. He did not know that the drivers had improved much since 1847; but the engines had been much improved as far as size was concerned, although not in regard to working.

For compounding a locomotive he had no hesitation in saying that the best plan to adopt was the tandem arrangement; because where there were two engines, one on each side, as in a locomotive, they must be made to work always in perfect unison. In the experiments recently made by Professor Kennedy on the engines of the s.s. "Meteor" (Proceedings 1889, page 243), the inequality of the work done in the three successive cylinders had been very marked. It had again been marked in the triple-expansion engine in Mr. Thornycroft's torpedo boat (Proceedings Inst. C.E., 1889,

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vol. xcix), in which, in the trials given in Table II (page 70), from 41 to 44 per cent. of the work had been done by the intermediate cylinder. That mode he maintained was not the proper way to work any compound engine, but was the way to break all the best cranks that had ever been made; and instead of paying for cranks, he thought it would be almost better to pay for a little more coal, and work non-compound.

No doubt the author would be able to explain the few points which had been enquired about in the discussion of the present paper; and he should be glad of an explanation also in regard to some of the indicator diagrams from the low-pressure cylinder, which showed almost a straight line on the top of the diagram.

He now wished to propose a most cordial vote of thanks to Mr. Urquhart, in which he was sure the Members would join, for all the trouble he had taken to enlighten the Institution as to his doings. It would be remembered that he was the only foreigner in Russia in an official engineering capacity on a railway who had been allowed to retain his nationality, which he thought was a very significant fact. He had also the pleasure of mentioning that the author had recently been awarded by the Emperor a large gold medal bearing an inscription for zeal; this was the second occasion upon which the same imperial distinction had been bestowed upon him, in recognition of the success he had achieved in developing the use of liquid fuel, which had now proved an enormous boon to the railways and other industries in Russia.

Mr. URQUHART wrote, in reply to the remarks made in the discussion, that he quite endorsed the views expressed in page 74 in regard to indicating a locomotive. The proper way would be to place an indicator on each end of each cylinder, and to have a corresponding set of observers to take all four diagrams simultaneously. But apart from the expense of using so many indicators, the construction of locomotives does not admit of this being easily

accomplished; and having himself only one indicator to work with, he regrets having been obliged to revert to long pipe connections and three-way cocks, in consideration of which the mean effective pressure indicated in each cylinder has been augmented in the tables by the very moderate addition of 10 per cent., as representing only approximately the loss of pressure due to these pipes and connections. The mean effective pressure as measured from the actual diagrams is also given in all cases without this addition, thus leaving it open to every one to make any such other allowance as his own experience may lead him to prefer. In Fig. 24, Plate 9, is shown the actual arrangement employed, in which the pipes are $\frac{3}{4}$ inch bore, and the nipples screwed into the cylinder ends have each a clear hole through them of $\frac{1}{2}$ inch bore, and the orifice at the other connections is nowhere less than $\frac{1}{2}$ inch clear bore. The pipes were well clothed, so as to reduce to a minimum the effect of cold. It may readily be admitted that 10 per cent. is considerably below the full allowance for the real throttling effect of these pipes and connections. The most striking example that has come to the author's knowledge of the difference between long and short indicator connections is that mentioned in a former discussion (Proceedings 1886, page 364), when it was stated that an increase of as much as 38 per cent. in the mean effective pressure had been found to result from the substitution of short for long connections. The indicator diagrams illustrating the present paper are careful copies of the originals, merely reduced in actual scale, but retaining nearly the same relative proportion, the high-pressure diagrams being here drawn to a pressure-scale of 80 lbs. per inch, and the low-pressure to one of 40 lbs. per inch, so that the areas of the diagrams from the two cylinders are nearly in the ratio of the piston areas, which is nearly one to two.

The plan of relieving the pressure on the high-pressure slide-valve, Figs. 16 to 19, Plate 8, the author regrets has now been found after further experience of its working to fail of accomplishing the object intended, and much steam leaked past the relieving rings. It has therefore been completely abandoned, without making any attempt to improve it. It is really an unnecessary complication, especially for the high-pressure slide-valve of a compound locomotive, which

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by virtue of the compounding is already considerably relieved by the receiver pressure on the area of the exhaust cavity on the under side of the valve. In the present case this area is $4\frac{3}{4} \times 12\frac{1}{4} = 58$ square inches, over which an approximate mean back-pressure of 50 lbs. per square inch gives a total relieving pressure of 2,900 lbs. Owing to this ample relieving pressure, the wear of the high-pressure slide has been very small indeed in the engines first compounded, which were turned out two years ago.

The arrangement of piston and connecting link for relieving the low-pressure slide-valve, Figs. 20 and 21, Plate 8, has not been brought forwards in the paper as a novelty, but is simply mentioned as a plan which the author has adopted, because, space permitting, it seems to him to meet a universal want; and as the result of his further trials on two locomotives he now finds it is giving perfect satisfaction. An analogous arrangement he understands is used in Worthington pumps of large size, where it gives satisfaction. All that is required is to make it in such a way that it cannot fail. Its efficiency he is glad to find confirmed by Mr. Head's experience (page 78); and the accident which led to his abandoning its use is of value in showing that large bearings are required for the pin joints of the connecting link, and that these ought to be thoroughly case-hardened and periodically examined: besides which, some precautions ought to be taken, so that, even should the pins give way, the piston should be prevented from being blown out of its cylinder, and thus being the means of stopping the engine. Of Mr. Head's valuable experience in this particular the author will certainly avail himself, by using every means to prevent the risk of any of his trains coming to a premature stop on the line through any such mishap with this appliance. The noise in the low-pressure valve-chest (page 87) was apparent only when running down hill without steam. In the locomotives in which this appliance was used by the author about ten years ago, the slide-valves were placed on the top of the cylinders, in the American fashion; and after some time of working, when the pins had got a little worn, the clatter was so great when running without steam that the author was obliged to abandon the plan. In the engines in which he has now reverted to it, the slide-valves are at the side of the

cylinders; and as in this position the weight of the valve and relieving piston has no effect as regards keeping the valve on or off the cylinder face, the arrangement gives favourable results. The area of piston which the author now uses, and which he considers ought not to be exceeded, is one-third the area of the exhaust cavity in the slide-valve.

The increased throw of the new eccentrics from $4\frac{1}{2}$ to $4\frac{3}{4}$ inches (page 75), giving the valves now a travel of $4\frac{1}{2}$ inches instead of their original travel of $4\frac{1}{4}$ inches, seems trivial in itself; and it was not so much for this small difference in valve travel that the author was obliged to change the eccentrics for both cylinders, as on account of the angle of advance, which with the original eccentrics was 30° for both forward and backward gear. So large an angle gave a dangerous amount of compression in the high-pressure cylinder for early cut-off. The new eccentrics, having angles of advance of 20° for both cylinders, give favourable diagrams for the notches mostly used; and the slight increase in their throw is rendered necessary by their diminished angular advance, as also for increasing the opening of the ports.

As to the proper capacity for the receiver in compound locomotives (page 76), there seems to be much difference still existing in opinion and practice; no hard and fast line has yet been definitely drawn for the capacity that gives the best results for the varying grades of expansion used in locomotive running. In order therefore to arrive at some idea as to the best capacity in practice, the author has been obliged to proceed tentatively; and in forming his own views on this subject he has been guided, not so much by the indicator diagrams or the power developed, as by the fuel bills resulting from lengthened working. It would manifestly be injudicious to increase the capacity to such an extent as to expose any portion of the receiver surface to the cold external atmosphere; and his attempts have therefore been directed to increasing the receiver capacity within the limits of the smoke-box, so as to expose as large a surface as practicable for catching or trapping as much of the waste heat as possible. This is the reason why the receiver capacity has as yet been increased by such small differences only as those mentioned in the paper (pages 58

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and 59), namely from 1·0 up to 1·3 and 1·8 times the capacity of the high-pressure cylinder.

In reference to the increased economy obtained from the compounded engines (page 76), those compared in Table 9 were doing exactly the same duties during the five summer months over which the comparison extended, with the result that a clear economy of 18·96 per cent. in fuel was attained in the goods engines, as due to compounding. At the same time a note was taken of running-shed repairs, which showed a decided economy in favour of the compounds; and although it would certainly be unreasonable to attribute all the economy in repairs to compounding, the author adheres to the opinion expressed in the paper, as the result of his own observations, that a certain economy in repairs must ensue from compounding, for the reasons set forth in page 53. The fuel economy shown in Table 9 is confirmed by Table 10, which has been drawn up from the running books for the whole year's working in 1889 of all the compounded goods engines in use, making altogether 206,355 engine-miles, with good bad and indifferent drivers, under varying conditions of weather, and with temperatures ranging from 15° below zero Fahr. in winter to 120° Fahr. in summer. The result is seen to be a mean economy of 17·74 per cent. in the fuel consumption per engine-mile; and the drivers being paid a premium for saving fuel, this result may be taken as conclusive. From the more recent results however, in October 1889 and the subsequent months, the author hopes that the mean economy will ultimately rise to about 20 per cent., too little time having as yet been allowed to the drivers for acquiring the special practical experience with compound locomotives that is so essential to success.

Respecting the reduction in tractive power after compounding (page 77), the first condition imposed upon the author, when consent was given to his proposals for compounding, was that the compounded engine should take the same load at the usual time-table speed after compounding as it did before, namely thirty loaded trucks up a gradient of 1 in 125. Although the compounded locomotives show a considerable reduction in tractive power at the earlier points of cut-off, yet in full gear they come up to within 5 per cent. of the

full tractive power they had before being compounded, as shown in Figs. 25 and 26, Plate 10. It is well known in locomotive practice that the boilers of non-compound locomotives, when working in full gear, cannot supply steam enough for a considerable distance, even at a slow speed, without lowering the water-level in the boiler; whereas the same locomotive when compounded steams easily when working in full gear for any desired distance and at considerable speed, without at all reducing the water-level in the boiler. In other words the capacity of the boiler is practically increased considerably by virtue of the engine being compounded.

Reverting again to the question of repairs (page 77), an example of the economy resulting under this head from compounding is afforded by a compounded passenger engine which ran a whole year without having its large piston looked at; and when the cylinder cover was taken off, the piston was found in such perfect order that nothing was done to it. It is true that some trouble took place with the stuffing-box of the high-pressure piston-rod, from the packing being burnt out, owing to the longer time during which the piston-rod packing is exposed to the great heat of the boiler steam in the high-pressure cylinder of the compounded engine. This is what induced the author to adopt M. Kubler's metallic packing, Plate 24, so successfully used on the Eastern Railway of France, which he is happy to find completely obviates the trouble he has hitherto had to contend with. He is glad to learn that Mr. Aspinall's experience with similar metallic packing (page 79) is favourable to its efficiency; and he agrees with him that the main objection to metallic packings hitherto has been their complicated construction. This has now been completely obviated by M. Kubler's exceedingly simple plan, for which the two sets of conical rings are made by running the special metal into metallic dies, thereby dispensing altogether with any machining or turning, and requiring very little fitting to the rods; should they not bear close upon the rod, they are slightly scraped just on the inside, the ends of each pair of semi-circular rings being kept 3-16ths inch apart to allow for wear.

In explanation of the point to which attention was drawn by Mr. Tomkins (page 77) in regard to the indicator diagrams, it will

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be noticed from page 55 and Table 1 that the first locomotive compounded, goods No. 35, had the high-pressure crank leading in forward running; and the diagrams in Figs. 29 to 32, Plates 11 and 12, taken from this engine, show a drop in the pressure in the low-pressure cylinder shortly after the beginning of the stroke. With the reverse sequence in goods engine No. 53, having the low-pressure crank leading in forward running, a somewhat different form of diagram is obtained from the low-pressure cylinder, Figs. 33 to 36, Plates 13 and 14; the admission line is here seen to be nearly horizontal through a longer period at the beginning of the stroke in the third and fourth notches, owing to the exhaust from the high-pressure cylinder taking place before the low-pressure piston has advanced much beyond the beginning of its stroke, thus reinforcing the pressure in the receiver, and keeping up the admission pressure longer in the low-pressure cylinder.

It is quite correct that locomotives burning liquid fuel do not require a strong blast to be produced by the exhaust (page 78). Even the author's compounded engines, having only two soft beats per revolution instead of four, steam very easily. There are no fire-bars, nor body of coal on the bars, through which air must be drawn by a powerful blast for supporting combustion; consequently in the low-pressure diagrams it will be noticed that very little back-pressure exists. The use of liquid fuel therefore is certainly advantageous to compounding, as pointed out by Mr. Aspinall, and goes far to account for the success which has attended the author's efforts in compounding. As there are now no practical difficulties in utilizing liquid fuel for locomotives, its profitable use on the Lancashire and Yorkshire Railway and elsewhere is simply a question of supply and of comparative cost. Of course if the fire-bars of an ordinary locomotive are so thoroughly covered up for burning liquid fuel only as to prevent any air from coming in through them, there must be some other means not mentioned in page 80 of admitting air to the fire-box for the combustion of the oil, otherwise than through the ashpan doors.

With regard to the plan of controlling by hand the non-automatic starting-valves (page 79), these were old valves already in stock, as

mentioned in the paper, having formerly been used on heavy locomotives for the Le Chatelier counter-pressure steam-brake, which has now been abandoned on the Grazi and Tsaritsin Railway. No doubt automatic action is an improvement, especially for compound locomotives; and the author has merely adopted the simple plan used in marine compound engines, which for his purpose answers admirably. For passenger locomotives, both a hand intercepting valve and a hand interchanging valve are added, as shown in Fig. 15, Plate 7, so that the engine can be made to run non-compound for any distance; these appliances are indispensable for starting passenger engines with heavy trains. In the compound goods engines neither of these valves is used, and the starting is effected simply by admitting a little boiler-steam into the receiver through the hand starting-valve S, Plate 2, if the high-pressure crank is on the dead point. The thirteen goods engines now compounded are all without intercepting and interchanging valves, having only the small hand starting-valve on the receiver; they are all working regularly, giving no trouble whatever. Certainly until the driver is used to such an engine some caution is required on his part at first, in order to handle the starting-valve in such a way as to prevent serious jerks. While admitting that an automatic intercepting valve is a decided improvement (page 80), the author has found from experience that the intercepting valve in his passenger locomotives, which is automatic in opening only and non-automatic in closing, serves its purpose very well; and where simplicity and low cost are an object, he finds it possible to dispense thus with all complications. Only one instance has yet occurred that he is aware of, namely in January 1890, when on account of much snow on the line the driver of a compounded passenger engine was obliged to resort to non-compound working for about ten miles at a slow speed. As there is no intercepting valve in the compounded goods engines, these cannot be worked non-compound, although it is possible in case of emergency to increase the power by admitting boiler-steam to the receiver; but this expedient is not resorted to in regular practice.

While it is true that inside-cylinder locomotives do not offer the same facilities as outside-cylinder engines for compounding

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(page 79), yet with the ready means of doing such work in the principal railway shops in England this objection with regard to inside-cylinder engines should presumably be overcome without serious difficulty or expense.

In regard to the relation of cylinder capacity to boiler pressure in compounding, the author quite agrees that even with steam of 120 lbs. pressure (page 82) compounds could work tolerably, only requiring proportionately larger cylinders. In compounding therefore with so low a boiler pressure, both cylinders would require to be new and of larger diameter.

The extent of the economy realised in the mill engine compounded by Mr. Walker many years ago (page 83) would manifestly depend upon whether it was a condensing or a non-condensing engine; in the latter case it would naturally be less than in a condensing engine. Having himself altered the shop engine at the Borisoglebsk works from an original single-cylinder non-condensing engine into a compound condensing with the same boiler-pressure, the author has found that a saving of as much as 25 per cent. in fuel has thereby been realised.

In the compounding so successfully carried out on the Saxon State Railways (page 84), it is interesting to learn that the ratio of 1 to 2·4 for the areas of the two cylinders has been found to give a better result than 1 to 2.

In order still further to satisfy himself about giving the preference to the high-pressure crank as the leading crank in compound locomotives in forward running (page 87), the author has now compiled from the fuel accounts the complete return given in Table 12 for the summer and winter months of last year 1889, showing separately the consumption of petroleum refuse in four compounded goods engines having the low-pressure crank leading in forward running, and in seven compounded goods engines having the high-pressure crank leading. The general result is a mean difference of $\frac{3}{4}$ lb. per mile, or from $2\frac{1}{2}$ per cent. in winter to 3 per cent. in summer, in favour of the high-pressure crank leading, thus proving broadly that this sequence of cranks is preferable; it will accordingly be adhered to in all future compounding.

TABLE 12.—*Comparative Consumption of Petroleum Refuse in Lbs. per Engine-mile in Compounded Six-wheel Coupled 36-ton Goods Locomotives with* Low-*pressure and* High-*pressure Crank leading in forward running, on the Grazi and Tsaritsin Railway in* 1889.

1889.	LOW-PRESSURE CRANK LEADING.				HIGH-PRESSURE CRANK LEADING.						
	No. 28.	No. 53.	No. 54.	No. 62.	No. 35.	No. 40.	No. 43.	No. 51.	No. 52.	No. 57.	No. 58.
SUMMER.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
April . .	...	21·57	...	...	22·89	...	...	...	28·32	19·58	24·21
May . .	...	25·35	...	...	21·68	23·26	...	...	24·54	23·94	24·26
June . .	...	24·31	...	...	21·29	22·62	18·15	...	22·65	24·12	21·86
July . .	...	22·60	...	...	24·58	21·26	22·45	...	24·38	...	22·09
August .	...	22·06	...	...	24·28	19·49	21·93	...	22·36	25·28	20·62
September	22·99	22·88	...	25·78	28·15	25·56	29·58	...	23·85	27·05	24·13
October .	25·45	25·97	26·41	27·03	25·54	23·62	24·41	...	25·49	23·34	24·90
Means in Summer	24·22	23·53	26·41	26·41	24·06	22·63	23·30	...	24·51	23·89	23·15
	Mean of Four engines **24·37** lbs.				Mean of Six engines **23·62** lbs.						
WINTER.											
January .	...	32·14	...	...	34·73	...	...	...	...	28·98	31·01
February .	...	33·89	...	...	25·03	...	...	...	...	27·27	26·39
March .	...	28·75	...	...	31·09	...	...	...	...	26·28	30·60
November.	27·79	27·77	26·11	25·36	27·01	24·83	26·26	27·32	28·14	24·51	26·11
December.	25·06	27·39	27·25	30·06	27·04	26·87	26·20	25·67	31·01	26·00	26·46
Means in Winter	26·42	29·99	26·68	27·71	28·98	25·85	26·23	26·49	29·57	26·61	28·11
	Mean of Four engines **28·32** lbs.				Mean of Seven engines **27·60** lbs.						
Whole Year	Mean of Four engines **26·26** lbs.				Mean of Seven engines **25·13** lbs.						

(Mr. Urquhart.)

The adoption of a variable differential cut-off, as suggested in page 87, would necessitate recourse to a separate reversing lever for each cylinder, or some other complication equally undesirable in locomotive practice.

The hump existing in the middle of the low-pressure diagram for the fourth notch in Fig. 32, Plate 12, with the high-pressure crank leading, is simply the consequence of a direct communication becoming opened between the two cylinders at that moment, a fresh influx of steam then entering the receiver from the high-pressure cylinder before the admission to the low-pressure cylinder is closed. Naturally the hump will become less as the capacity of the receiver is enlarged. Although it is certainly not the proper time for more steam to enter the large cylinder after 40 to 50 per cent. of its stroke has already been accomplished, yet in the present case this is unavoidable, owing to the sequence of cranks and to the limited capacity of the receiver, the latter being only 1·14 times the capacity of the high-pressure cylinder in No. 35 engine from which the diagrams in Figs. 29 to 32, Plates 11 and 12, are taken. By enlarging the receiver, the author is of opinion that more power is got out of the high-pressure cylinder, because the back-pressure in that cylinder is then less; whilst at the same time the lower mean pressure of steam in a larger receiver develops less power in the low-pressure cylinder; and thus an enlargement of the receiver tends to equalise the power developed in the two cylinders, wherever it has previously been greater in the low-pressure than in the high-pressure cylinder.

For winding engines (page 89) compounding seems to the author to be not so convenient as for locomotives, except for winding from great depths or for hauling up long inclines, where a compound engine of small power and short stroke would work well if geared up; for a direct-acting engine with long stroke, winding through a short lift, he thinks compounding would be found inconvenient. For reducing the pressure of the boiler steam before admitting it direct to the low-pressure cylinder for starting, a variety of ingenious plans have been devised; but in his compounded locomotives he gets over this difficulty by using a short direct pipe connection between the main steam-pipe and the receiver, having no more than $1\frac{1}{4}$ inch clear

bore, with a hand stop-valve of $1\frac{1}{4}$ inch clear steam-way; in the compound working this valve is always kept tight closed by the boiler pressure on the top of it.

Since the author's previous papers on the use of petroleum refuse as fuel in locomotives, the plan has been adopted on two railways higher up the Volga, namely the Rybinsk and Bologoi and the Moscow and Yaroslav, both abutting on the Volga above Nishni Novgorod: new regulations having now come into force for restricting the cutting down of forests. Also on the following railways in the centre of Russia:—Moscow and Brest, Moscow and Riazan, Riazan and Kosloff, and Baschuntchack; the last is a line on the Asiatic side of the Volga, abutting on the river below Tsaritsin, and has been specially made for the transport of salt from lakes about fifty miles from the river. As to the success of petroleum refuse as fuel (page 90) there can be no doubt; at the present time probably about a thousand locomotives in Russia are burning nothing else; and its use is yearly extending rapidly, not only for generating steam, but the author has successfully applied it also to copper smelting and brewing beer. Wherever used it is attended with great economy and cleanliness. On the Grazi and Tsaritsin Railway the clear saving in the locomotive working as compared with coal is 45 per cent. before compounding; and now, with the further economy of 18 per cent. due to compounding, the total saving amounts to $45 + 0{\cdot}18 \times 55 = 55$ per cent. in compound locomotives burning petroleum refuse, as compared with ordinary locomotives burning coal. This saving goes far to increase the dividends of the railway, besides allowing of considerable reductions in the rates. In special trials an economy of 22 per cent. was attained in compounded goods engines, and over 21 per cent. in compounded passenger engines; but a mean economy of $17\frac{3}{4}$ per cent. is the result of broad data, including good bad and indifferent practice over the whole year 1889, as seen from Table 10. The fuel allowance has now been reduced by 15 per cent. for the compounded locomotives; but notwithstanding this reduction, the drivers save 3 per cent. out of their present allowance. The quantity of oil and tallow used by the compounds is no more than for ordinary locomotives, while the cost of repairs is certainly less.

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With regard to the drivers (page 92), less depends upon their skill in the firing of locomotives burning liquid fuel, because the fuel is here supplied mechanically and continuously. Yet even in this case some of the drivers by great care manage to burn less liquid fuel than others on the same engine.

With the object of determining the comparative consumption of water in the compounds and the non-compounds, the author has also made a trial with both goods and passenger locomotives on the same section of line and with the same weight of trains, the two goods engines on one day and the two passenger engines on the two days following. The goods compound gave an economy of 26 per cent. in water consumption, at the same time as an economy of 18 per cent. in fuel consumption. The passenger compound gave an economy of $34\frac{3}{4}$ per cent. in water consumption; but it would not be safe to put all this down to compounding, as the weather on the second day was much in favour of the compound passenger engine. On a former occasion an economy of 30 per cent. of water was attained in goods compounds; and therefore from 26 to 28 per cent. of economy in water consumption may safely be attributed to compounding at equal boiler pressures. Although on the Grazi and Tsaritsin Railway the water costs no more than the liquid fuel to pump it to the stations, including wear and tear of machinery, yet even here, apart from the cost of extra fuel, the saving of water is of importance as raising the efficiency of the existing sources of supply, some of which from wells are deficient. For railways running through deserts this is a point of very great importance.

Tandem compound locomotives (page 93) have been objected to on account of their complication and difficulty of access to the pistons. The only instance to the author's knowledge of a tandem compound locomotive used in Great Britain was that of Mr. Nisbet's design on the North British Railway, which he understands was abandoned because the extra cost for repairs &c. was not recouped by the economy in fuel. On the continent there are several tandem compound locomotives; but to all appearance there does not seem to be a future for them.

The eight-wheel coupled 48-ton goods locomotives (page 60) are the only kind of goods engines that have been built during the last ten years for the Russian main-line railways. For heavy trains at slow speeds, especially on single lines, these engines present several advantages: they draw trains of 720 tons gross weight in summer up gradients of 1 in 125, which is 50 per cent. more than can be done by the six-wheel coupled 36-ton goods locomotives, while their consumption of fuel and water is only 30 per cent. more. Since the reading of the paper, one of these engines has now been compounded, as shown in Figs. 68 to 74, Plates 25 to 28. This particular engine, No. 68, was built by Messrs. Sharp Stewart and Co. in 1874, before the building of eight-wheel locomotives had been begun in Russia; it is one of a number then built by them for the Volga Don Railway, which has since been amalgamated with the Grazi and Tsaritsin, and has ten miles of gradients of 1 in 66, necessitating these powerful engines. The main dimensions before compounding are:—cylinders 20 ins. diameter and 26 ins. stroke; wheels 4 feet diameter; 207 iron tubes of 2 inches outside diameter and 15 ft. 9 ins. length between tube-plates; heating surface, fire-box 118 sq. ft., tubes 1,697 sq. ft., total 1,815 sq. ft.; fire-grate area 19 sq. ft.; boiler pressure 9 atm. = 135 lbs. per sq. inch above atmosphere; Stephenson link-motion. The compounding was effected simply, without even lifting the engine off its axles. The new low-pressure cylinder of $27\frac{9}{16}$ inches diameter is placed on the right-hand side, and drives the following crank; the original 20-inch cylinder on the left-hand side is retained as the high-pressure cylinder, driving the leading crank. The whole of the compounding arrangement is similar to that carried out in the other engines, as described in the paper, with the exception only that, while the high-pressure cylinder remains quite horizontal, Fig. 70, in line with the centres of the axles, the low-pressure cylinder on account of its larger diameter has had to be raised above that level, Fig. 69, so as to run clear of the station platforms and keep within the profile of the cross section allowed for the rolling stock. Its centre line is accordingly inclined downwards to the centre of the main driving axle, Fig. 68, and forms an angle of two degrees with the horizontal, the

TABLE 13.

Mean Steam Pressures, and Temperatures of Steam,

in Eight-wheel Coupled 48-ton Compounded Goods Locomotive No. 68.

High-pressure Crank leading in forward running.

See Indicator Diagrams, Figs. 75 to 80, Plates 29 to 31.

Cylinder.	Cut-off.	Steam Pressures, lbs. per square inch.					Temperatures of Steam.			
	† Percentage of Stroke.	Valve-chest.	Mean Forward.	Mean Back.	Mean* Effective. D	D × 1·1	Beginning of stroke.	End of expansion.	Utilized in expansion.	Utilized in both cyls.
	Per cent.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Fahr.	Fahr.	Fahr.	Fahr.
High-pressure, left hand.	30	135	88	64	24	26	349°	291°	58°	
	40	138·7	109	60	49	54	356°	312°	44°	
	50	146	117	70	47	52	359°	319°	40°	
	60	138·7	120	65	55	61	353°	329°	24°	
	70	140	127	64	63	69	356°	334°	22°	
	75	142·5	131	65	66	73	356°	338°	18°	
Low-pressure, right hand.	30	63	33	8	25	28	307°	235°	72°	114°
	40	74	49	5	44	48	319°	266°	53°	90°
	50	75	55	3	52	57	319°	273°	46°	86°
	60	73	57	3	54	59	319°	278°	41°	75°
	70	75	63	2	61	67	319°	291°	28°	65°
	75	76	64	2	62	68	319°	293°	26°	63°

† The point of cut-off in percentage of stroke is given as denoted by the index of the reversing screw.

* The mean effective pressure in column D is the difference between the mean forward and backward pressures; in column D × 1·1 it is increased by 10 per cent. to allow for the throttling effect of the indicator pipe and connections.

TABLE 14.

Power developed by Eight-wheel Coupled 48-ton Compounded Goods Locomotive No. 68.
High-pressure Crank leading in forward running.

Cylinders 20 ins. and $27\frac{9}{16}$ ins. diameter, 26 ins. stroke. Wheels 4 ft. diameter.

Adhesion Weight 48 tons. Boiler Pressure 135 lbs. per square inch above atmosphere.

Cut-off. † Percentage of Stroke.	Speed of train. Miles per hour.	Driving Wheels. Revolutions per minute.	Piston Speed. Feet per minute.	Indicated Horse-Power.	Tractive Power.	Ratio of Tractive Power to Adhesion Weight.	
Per cent.	Miles.	Revs.	Feet.	I. H. P.	Tons.	Per cent.	Ratio.
30	12	83·6	361·8	268	3·871	8·1	= 1 to 12·4
40	12	83·6	361·8	504	7·292	15·2	= 1 to 6·6
50	12	83·6	361·8	556	7·999	16·7	= 1 to 6·0
60	12	83·6	361·8	618	8·607	17·9	= 1 to 5·6
70	12	83·6	361·8	679	9·819	20·5	= 1 to 4·9
75	12	83·6	361·8	700	10·037	20·9	= 1 to 4·8

† The point of cut-off in percentage of stroke is given as denoted by the index of the reversing screw.

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front end of the cylinder being raised about 6 inches above the centres of the axles. To this slight extent therefore the low-pressure cylinder works diagonally; but on testing the engine with a full train no vertical disturbance was noticed on the low-pressure side, notwithstanding the vertical force which must be set up by the diagonal action on that side. The piston-rods extend through the front cylinder-covers, for supporting the heavier pistons. The receiver is 1·5 times the capacity of the high-pressure cylinder. There are sixty engines of this class on the Grazi and Tsaritsin Railway, all of which in time will be compounded.

In Tables 13 and 14 (pages 108 and 109) are given the mean steam pressures and the temperatures of steam and the power developed in this engine for the six grades of expansion denoted by the index of the reversing screw for cut-off at from 30 per cent. to 75 per cent. of the stroke; and in Figs. 75 to 80, Plates 29 to 31, are shown the corresponding indicator diagrams from both cylinders. It will be noticed that there is rather too much compression at the early cut-off; but the author did not wish to go to the expense of having new eccentrics put on to obviate this, and he thinks it will not be found necessary to do so, because a fair diagram is obtained for the grades of expansion that are most used. The throw of these eccentrics is 7·10 inches, in consequence of the eccentric-rods being here attached to the very extreme ends of the links, instead of nearer to the middle as in the six-wheel engines; the angle of advance, both forward and backward, is 10°. The valve gear was not in any way repaired when compounding, which accounts for the trembling of the indicator in taking the diagrams. The inside lap has been taken off the high-pressure valve, which has now neither inside lap nor clearance.

The low-pressure slide-valve is relieved by the connecting link and piston shown in Figs. 72 and 73, Plate 28; the area of the piston is made one-third of that of the exhaust cavity in the valve itself, which is found to answer very well. The accident described by Mr. Head (page 78) has been turned to the best account by making the pins large in the connecting link; they are 1·57 inch diameter, and work in brass bushes, so as to be renewed occasionally; and advantage is taken of the relieving cylinder being horizontal in this case to

put the pins in with their heads at top, so that they cannot of themselves drop out. For the high-pressure cylinder the Trick valve, Fig. 74, Plate 28, has been substituted in place of the original ordinary slide-valve; its full travel is $4\frac{1}{2}$ inches, as is also that of the low-pressure valve.

For the very kind manner in which his isolated labours have been referred to by the President and other speakers in the discussion, the author desires to express his grateful thanks.

ON THE BURNING OF COLONIAL COAL IN THE LOCOMOTIVES ON THE CAPE GOVERNMENT RAILWAYS.

BY MR. MICHAEL STEPHENS, CHIEF LOCOMOTIVE SUPERINTENDENT.

South African Coalfields.—The existence of Coal in South Africa was not generally known until within the last sixteen years; for although in 1864 an opening was made by Mr. George Vice into an outcrop at a place in the Stormberg mountains in the north-eastern part of the Cape Colony where the village of Molteno now stands—as shown in the map of South Africa, Fig. 1, Plate 32,—the quantity extracted for many years afterwards was too small to attract notice, owing to the isolated position of the place and the poor quality of the coal near the outcrop; and it was not until the line known as the eastern system of the Cape Government Railways—from the port of East London to its former terminus at Queenstown, a distance of 154 miles—was under construction, that the possibility of working it with colonial coal received consideration. A mining engineer, Mr. F. W. North, was engaged to examine the colonial coalfields, and his report published in 1878 showed that the area of coal-bearing land was much greater than had been generally supposed. Boring operations undertaken by him to prove its extent were stopped by the outbreak of the Kaffir war in 1877–78; but fresh discoveries made between that date and the beginning of last year, partly on territory which at the cessation of the war in 1880 (Tembu rebellion) became government property, showed that the quantity of coal which can be made accessible by a branch railway from the eastern system will suffice for the requirements of the existing colonial railways at the present rate of consumption for about three centuries; whilst occasional outcrops in a north-easterly direction indicate the probability of the continuity of the coal beds through Pondoland to the borders of the colony of Natal.

The existence of extensive coal beds in Natal of a rather better quality than any yet found in the Cape Colony has long been known; but owing to the absence of any local demand, and the prohibitory cost of transit by ox-wagon, they were almost unworked until recently, when the railway from the port of Durban was extended sufficiently near them to admit of a portion of the supply for the locomotives being conveyed to the line. An extension of the railway to the Transvaal border, now in progress, will admit of the coal being put direct into the trucks, when it is anticipated that the Natal Railways will be worked exclusively with local coal, and that the coasting steamers will also be supplied with it. Mr. William Milne, locomotive superintendent of the Natal Government Railways, considers that some descriptions of Natal coal are almost equal in steam generating properties to South Yorkshire coal, which was exclusively used formerly on the Natal Railways.

Outcrops of coal also occur in the Orange Free State and the native territory of Basutoland on the north-eastern border of the Cape Colony; but little is as yet known concerning them, with the exception of that at Kronstad in the north of the Free State, where an extensive coalfield exists, the working of which for the supply of the Kimberley diamond mines has recently been commenced; but, as in the case of the Cape and Natal coal, the operations are restricted by the cost of transport by ox-wagon. In the Transvaal Republic, north of the Free State, the discoveries of gold, which have given such a remarkable impetus to the railway traffic and trade of South Africa generally, are rivalled by those of coal. Seams of from seven to fourteen feet thickness, of both steam and bituminous coal, are being met with and worked to supply the extensive demand at the gold mines. Some of the Transvaal coal is superior in quality to any yet found in the Cape Colony, Natal, or the Orange Free State.

The total coal area of South Africa is thus summarised by Mr. W. Galloway of Cardiff, the mining engineer engaged by the Cape Government last year 1889 to make a special report on the Stormberg and Indwe coalfields in the eastern part of the Cape Colony, preparatory to the required connections being made for

distributing the coal over the colonial railway system:—"The coalfield of South Africa covers a fairly symmetrical area, embracing parts of the Cape Colony, the Orange Free State, the Transvaal, Natal, and the whole of Basutoland. .... The greatest length and breadth of the coalfield contained within this boundary line are 500 and 200 miles respectively, and its area is about 56,000 square miles. .... Up to the present its fringe has just been touched in a few isolated and far-distant points; and it is certain that further systematic researches will be rewarded by the discovery of great stores of mineral fuel, capable of supplying the wants of South Africa for many generations."

Stormberg Mines.—The extension of the Eastern Railway, from the former terminus at Queenstown to the town of Aliwal North on the Orange River, passes through the Stormberg coalfield; and though, as regards the quality of the coal and cost of mining, the Indwe coalfield, 58 miles north-east of Queenstown, possesses great advantages over the Stormberg, the absence of railway communication has hitherto rendered it necessary that the supply for the working of the eastern system should be obtained from the two Stormberg mines known as the "Molteno" and the "Cyphergat." The latter mine, 204 miles north of the port of East London and 5,450 feet above sea-level, has the advantage of direct communication with the railway; the trams from the horizontal openings in the hill in which the coal is found are tipped upon the screens which deliver into the trucks; and the quality of the coal is rather better than the Molteno. The coal with which the eastern system has been worked for the last four years, to the exclusion of imported coal, has therefore been obtained mostly from the Cyphergat mine; and it is the mechanism employed in burning this coal which the present paper is intended to describe.

Coal Burning in Locomotives.—The Cyphergat coal is bituminous and gaseous, gives out a great heat, and generates steam rapidly as long as the grate is fairly clean; but it contains about 29 per cent. of incombustible matter, which becomes partially fused, and forms a

pasty mass underneath the incandescent coal, and thus checks the generation of steam by preventing the admission of air between the fire-bars. Attempts were made to overcome the difficulty by means of tipping grates, rocking bars, and other contrivances; but these were not successful, and hand-labour was resorted to. The firemen were selected for strength and powers of endurance; the fire-bars were spaced 3 inches apart, that is with 3 inches clear open space between them, and the spaces were kept clear by pushing the semi-fused dross through them with the pricker. Owing to the gauge of the railway being 3 feet 6 inches, the narrowness of the fire-box renders the grate area sufficiently accessible for the purpose through a fire-hole of the ordinary size. The dross fell between the rails through openings in the ashpan; and as pieces of burning coal were pushed through with it, the progress of a train at night was marked by a streak of fire between the rails. Occasional halts had also to be made for removing through the fire-hole masses of dross which had become set; but apart from such delays the traffic was efficiently worked on a line abounding in gradients of 1 in 40 and five-chain curves. The work of the firemen however was exceptionally severe, being closely akin in that respect to puddling; and even the prospect of speedy promotion could hardly induce them to stop at it.

Movable-Bar Grate.—The difficulty has been overcome by the introduction of the movable-bar grate, which is the invention of Mr. J. D. Tilney, locomotive superintendent of the eastern system of the Cape Government Railways. In Figs. 3 and 4, Plates 33 and 34, is shown its application to an outside-cylinder engine with six wheels coupled of 3 feet 6 inches diameter and a four-wheel bogie, and with cylinders 15 inches diameter and 20 inches stroke, and the ordinary link-motion: a type of engine much used on the Cape Railways, of which a general side elevation is shown in Fig. 2, Plate 33. The fire-bars, eleven in number, which are of cast-iron and spaced $1\frac{1}{2}$ inches apart, rest on racks placed near their ends, and have serrated tops. The five alternate bars B are $1\frac{1}{2}$ inches shorter than the others, and have each a lug projecting downwards. A long

pin goes through the lugs, and through the ends of two rods R which pass from the pin through slots in the damper to the front axle, on which is fixed a drum D. The rods are connected to crank-pins in another drum M, which the engine-driver can bring into contact with the drum on the axle by means of the hand lever L, as in the chain-brake arrangement. A longitudinal reciprocating motion of $1\frac{1}{2}$ inches is thereby imparted through the rods to the five alternate bars B; and the dross which has settled on the serrations, being cooled by the air from below, is broken up when the bars are put in motion, and falls through doors O O in the ashpan, which can be opened and closed from the foot-plate by the handle H. The dross when set is friable, and not hard like ordinary clinker; and the grate is kept clean by putting the bars in motion occasionally for about ten seconds at a time. Fire cleaning during a journey is thus dispensed with, and the firing of the engines by men of ordinary powers of endurance is rendered practicable. The mechanism is simple and durable; and its introduction has rendered practicable the efficient working of the traffic on an exceptionally heavy line, with the inferior coal, containing 29 per cent. of dross, which crops out on the western boundary of the Cape coalfield.

Extent of Working.—The length of line now worked with colonial coal amounts to 280 continuous miles of main line and 12 miles of branch line. In its general features the line is extremely undulating, with a ruling gradient of 1 in 40, and a minimum radius of curvature freely used of 5 chains (330 feet); the highest elevation attained above sea level is 5,420 feet. The gross load taken by the engines is 102 tons, exclusive of the engine itself. An analysis made in Cape Town furnishes the following particulars as to the quality of the coal:—specific gravity, 1·48; volatile constituents, 15·32 per cent.; coke, 86·68 per cent.; ash, 29 per cent. The price of the coal at the Stormberg mines is 14*s.* per ton; at the Indwe mines, which are not yet accessible by rail, the price is 7*s.* per ton.

Discussion.

Professor ALEXANDER B. W. KENNEDY, Vice-President, suggested that in the analysis of the coal, given at the end of the paper, the percentage of the volatile constituents ought to be 13·32 instead of 15·32, or else that the percentage of coke ought to be 84·68 instead of 86·68; because then the volatile constituents and the coke would add up to 100, as he presumed ought to be the case. The ash he supposed was all included in the coke.

Mr. WILLIAM GALLOWAY, having made the special report on the Stormberg and Indwe coalfields, referred to in pages 113 and 114 of the paper, mentioned that the part of the coalfield over which he had travelled extended from the neighbourhood of Molteno, Fig. 1, Plate 32, past the Indwe mines, for a distance of fifty or sixty miles towards the north-east. The outcrop of the coalfield, as described by Mr. Dunn and some other geologists who had examined it, extended from the Molteno mine up through the Orange Free State into the Transvaal. Thence it stretched towards the north-east, and turning back southwards passed along the western boundary of Swaziland, and kept more or less parallel to the east coast, until it reached the Indwe mines, and then turned westwards to Molteno. The Indwe and the Molteno mines were at the outcrop. At present indeed the coal was known only at the outcrop. No shafts had as yet been sunk in any part of the coalfield, except in the Transvaal and in Natal, where some few shallow shafts had been sunk lately. The mining was of a very rudimentary character, so far as it had been pursued.

One of the first things that struck any one accustomed to the coalfields of England and the continent was the regularity of the strata in the Cape coalfield; the hill sides were entirely free from deposits of earthy matter, with the exception that between the beds of hard rock there were short slopes of débris; but the hard rocks themselves stood out exposed to view everywhere along the hill sides, presenting a very peculiar appearance. On observing

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those rocks from a distance of a few miles, it was seen that they lay almost perfectly horizontally, that there were no contortions, and that there were few dislocations of any kind. The coal measures were included between red rocks which lay above them, known locally as the Red Beds ; and red, buff, and mottled rocks which lay below them, and were locally called "Karroo." In this respect they resembled to some extent the Coal Measures of England, where there were also red rocks above and below ; and the appearance of the Cape beds would almost lead to the supposition that they were similar in age to the English Coal Measures. Geologists who had examined them of late years were coming he believed to the conclusion that they nearly corresponded with the English Coal Measures ; and he had recently been told that some fossils had been found which tended to prove that this was the case.

The coal measures were only about 1,000 feet thick in Cape Colony—a small thickness when compared with those of the Welsh coalfield, which were about 12,000 feet thick in the thickest part. Furthermore in Cape Colony there was only one seam of coal of any consequence in that thickness of 1,000 feet. That one seam of coal towards the west contained 22 or 23 inches of good coal ; and eastwards, towards the Indwe mines, it contained about 4 feet or a little more. It bore the same character throughout, consisting of alternate beds of coal and shale, the latter varying from perhaps 15 or 18 inches down to 8 or 9 inches, and the coal beds from 3 inches up to 2 feet 2 inches, none of them being thicker than 2 feet 2 inches. Those shale beds would be considered a source of trouble and expense in England ; but inasmuch as the seam contained the same shale beds throughout its whole extent, the conditions were identical in this respect in the different mines. The roof of the seam was remarkably good as a rule, consisting of hard sandstone. One peculiar feature of the South African coalfield was that it was intersected by volcanic rocks to an enormous extent. There was no parallel to it in Europe that he was aware of. The whole country was seamed through with dykes and horizontal sheets of the basalt rock "dolerite." In riding along the edge of the coalfield, sometimes for ten or fifteen miles, no outcrop of coal could be found, the whole

being hidden by masses of volcanic rocks; and the scenery of the whole country owed its peculiar appearance to those volcanic rocks. The dolerite had rendered the coal anthracitic in every part where it approached the seam; and had thus made it practically useless for any purpose at present known, on account of the large percentage of ash, to which Mr. Stephens had referred.

The analysis of the coal having been given in the paper, he would only amplify that portion of the subject by saying that part of the mission which he had had to perform for the colonial government had been to test the relative qualities of the coal from two different areas of the coalfield, namely Molteno and Indwe; and also to compare them with those of Welsh coal. For that purpose he had spent about a week on a locomotive with a loaded train, the whole amounting to 142 tons; and had run the train between East London and Blaney, a station about thirty miles up the railway, on which there were heavy gradients, the rise altogether amounting to about 1,000 feet; the train was run from East London and back, once and sometimes twice in a day. The result of the trials showed that, on the locomotive employed for these tests, Welsh coal evaporated 8·76 lbs. of water per lb. of coal; Indwe coal, which was that from the mine furthest to the east, evaporated 5·62 lbs.; and Molteno coal evaporated 5·04 lbs. These were the results of a number of trials with the different kinds of coal. The locomotive was fitted with Mr. Tilney's movable fire-bars, as described in the paper; and he could bear testimony to their great efficiency, and to the great saving of labour to the firemen in consequence of their use. The locomotive had a fire-brick arch in the front end of the fire-box, as shown in Plate 34; and before commencing the trials he had another arch put in at the back end just over the door, sloping down to within about 15 inches of the front arch, so as to deflect the air that was admitted at the door down on to the top of the fire. His experience had been that with the great amount of ash produced by the coal the draught up through the fire-bars was very weak; and as a consequence a great deal of the combustible matter escaped up the chimney unburned, producing vast clouds of smoke. In order to avoid that waste, he had caused the fire-doors to be opened to a greater

(Mr. William Galloway.)

or less extent according to the condition of the fire at the moment, whereby some considerable saving of fuel had been effected.

The length of railways now opened in the colony was as follows. On the eastern system 292 miles, from East London up to Aliwal North; on the midland system up to De Aar, including the branches to Graaff Reinet, Port Alfred, and Colesberg, 633 miles; on the western system up to Kimberley, including the branches near Cape Town, 774 miles. As yet colonial coal was used only on the eastern system; and one of the great objects of the government in having the coalfields surveyed was to ascertain whether there was likely to be sufficient coal for supplying the railways for a certain number of years, as it was contemplated to make a railway across between the eastern system and the midland, through a country which would not pay for the construction of a railway. That junction line would be made principally for the purpose of carrying coal across from the eastern to the midland and western systems. There was also an intention of making another railway, 58 miles long, to connect the Indwe mines with the eastern system, so that the Indwe coal might be brought on to the eastern railway, and might perhaps to some extent replace the thinner and rather less economical coal worked at Molteno. From the Indwe mines the railway was further intended to pass by Molteno across to Middelburg on the midland line; and the coal was then expected to travel northwards up to Kimberley, and southwards down towards Cape Town, over the western line.

Having been asked to report on that part of the question also, he had made calculations to ascertain how far the colonial coal could compete with English coal. Taking English coal at 36*s.* per ton delivered at Cape Town, which was about the price when he was there, and colonial coal at 5*s.* per ton at the Indwe mines, he had made out that the colonial coal could travel down towards Cape Town—taking the railway carriage at 0·625 penny per ton per mile, which was the lowest rate that the general manager could allow—to within about 340 miles of Cape Town, and would there be as economical as Welsh coal; but not further. Welsh coal being so much better in quality, although so much dearer, was able to

travel up to a distance of about 340 miles from Cape Town to meet the colonial coal. Of course the present higher price of Welsh coal would now alter that calculation to some extent, and enable the colonial coal to compete with it down to a point still nearer to Cape Town. The saving by the use of Indwe coal over the whole of the colonial railways he had estimated at £58,000 a year.

Mr. H. W. WHITE said that in 1879 he had tried a sample of Natal Newcastle coal at the Cape of Good Hope dockyard. It was only a small trial, the whole quantity being no more than about 4 tons; and the coal itself had the appearance of coming from near the outcrop. The result was fair, the evaporative effect being nearly 70 per cent. of that of the mixed English coal then generally used in the dockyard. The quantity of ash and clinker was rather large, but not more than might be expected in coal from the outcrop. In 1882 the price of English steam coal at Cape Town went up to £6 a ton; and 23 miles from Cape Town, at Simon's Town, where he was at the time, it was £7 a ton, and very little was to be had at that price, owing to a war scare. The advantage of having coal in the colony was therefore obvious, both from the merchants' point of view and also from that of the colonial steam-users, a class now becoming numerous and important. At that time a large proportion of the steam used in the colony was raised from wood, and sometimes from cow-dung when wood could not be got: in fact from anything that could be burnt.

With regard to the arrangement of the movable fire-bars described in the paper, he thought possibly the serrations on the bars might be somewhat too fine to be durable; and also that the driving gear for actuating the bars would be rather apt to slip whenever they struck into a particularly hard piece of clinker.

The PRESIDENT asked whether the colonial coal had been used at all for marine purposes, to which an allusion was made in page 113 of the paper.

Mr. WHITE replied that the Indwe coal was used in steamers calling at the port of East London. Tugs and such steamers used it

(Mr. H. W. White.)
almost entirely, and satisfactorily: that is, for coasting and towing purposes.

The PRESIDENT asked how the large amount of cinder or dirt was got rid of on shipboard.

Mr. WHITE replied that the furnace of a marine boiler could be much more easily dealt with in cleaning the fires than the fire-box of a locomotive. It was on a fair level with the fireman, and if once he could bring the clinkers up from the bars there was no difficulty in pulling them out. There was of course a considerable amount of work in sending so much more ashes overboard, but that was all.

Mr. STEPHENS wrote that the serrated fire-bars lasted considerably longer with the colonial coal than the plain fire-bars did with the Welsh coal, because the dross from the colonial coal protected the serrations from the action of the incandescent coal. In the preliminary trials the bars had been moved by an eccentric, for which the frictional driving gear had been substituted in order to obviate the chance of breakage in the event of the motion being checked by hard clinker; but the quantity of hard clinker formed was so small that it gave no trouble, and the friction gear did not slip (page 121) unless oil got on the drums.

The consumption of Stormberg coal per train-mile was slightly more than double that of the best Welsh steam coal. The consumption of the coal from the Indwe mines was about 60 per cent. in excess of Welsh.

The Indwe coal used in the tug steamers in the port of East London was found to answer very well, even when disabled ships had to be towed to Port Elizabeth, a distance of 150 miles. No attempt to use it on a long voyage had yet been made.

Mr. JEREMIAH HEAD, Past-President, asked whether any attempt had ever been made to wash the colonial coal. Such good results had been obtained in the north of England and elsewhere from washing dirty coal, whereby the ash was reduced from 15 or 16 per cent. down to

5 or 6, that the most obvious way to deal with this colonial coal in the first instance would seem to be to wash it, which could now be done at a small expense both of labour and of water. Also had any attempt been made to coke the coal?

Mr. GALLOWAY replied that no attempt had yet been made to wash the coal. The coal as used was in lumps, which did not contain any visible earthy matter; consequently washing would not be of so much use as careful hand-picking. Recently he had sent out drawings for a small hand-washing machine to Mr. Stephens, who was anxious to wash the small coal; but beyond this nothing had yet been done. Some attempts to coke the coal had been made he believed on a small scale at East London by Mr. Tilney; but he had not succeeded in making coke that would be suitable for any purposes.

Mr. WHITE added that the probable reason the coal had not been washed was the want of water, a want which made itself felt in many industries in Cape Colony to an extent hardly realised in this country.

Mr. WILLIAM SCHÖNHEYDER asked whether, when the experiments were made with Welsh coal in the locomotive, it had proper fire-bars suitable for Welsh coal; or whether the same bars were used that were employed for the colonial coal.

Mr. GALLOWAY replied that Mr. Tilney's serrated fire-bars were taken out for the experiments with the Welsh coal, and ordinary bars were substituted. It would be noticed from the drawings however that the locomotive had a relatively large fire-box, much larger in proportion than the fire-box used in England; and consequently the Welsh coal might not have been tried under as advantageous circumstances as it would have been in a smaller fire-box.

Mr. CORBET WOODALL mentioned that in the north of Natal coal was now worked extensively. Two years ago it was being opened

(Mr. Corbet Woodall.)

rapidly in Natal, and the railway was being carried forwards from what was then the terminus at Lady Smith towards Dundee and Newcastle, so as to bring the coal down to the port at Durban. The railway was not of a kind suitable for developing traffic of that sort rapidly, because it contained a great number of long gradients of 1 in 32; and the bridges crossing the valleys were of such a slight build that the train had to be pulled up in order that a man might get on and go across the bridge with it, so as to ensure that it should not go across faster than at a certain slow speed; then the man waited for the return train, mounted it, and went back again. The curves also were extremely sharp. The coal in Natal was much superior to that now described as worked in Cape Colony; and he had no doubt that, when the railway facilities were improved, it would be brought down to Durban and the east coast, not only for locomotive purposes, but also for the working of the coasting steamers. In the samples which he had brought home of the Natal coal the ash did not exceed 12 per cent. He had tested them for gas-making, and had found that for this purpose they were nearly equal to coal from the Durham coalfield. Mr. Galloway had referred (page 117) to the rudimentary mode of working the colonial coal; and allusion had been made in the paper (page 113) to the cost of transit by ox-wagon or "trecking." At one colliery that he had visited he had been lowered by an ox, which backed to let him down, and went forwards to pull him up; and that was the way in which the coal was raised from the pit. The method of carrying by ox-wagon was so crude, and so cruel to the oxen, that it was impossible to carry heavy loads except at an enormous cost. The drivers of the teams of oxen, called transport riders, were all Boers, and they used stones to scotch the wheels for resting the oxen in going up hill; but he had never seen them move any stones out of the way, whether deposited by themselves or by anyone else. At the best the roads were bad enough, and in this way they were made still worse.

Mr. WILLIAM B. TRIPP said he had read the former reports on the colonial coal by geologists and others, and had understood from them that it was of a different character from the English coal, the latter

being supposed to have been formed on the site where the plants composing it had formerly grown; while colonial coal was supposed to have been brought down by water, and deposited in conjunction with earth, sand, and other matters; and this supposition would to a large extent account for the amount of ash found in it. He should be glad to know whether Mr. Galloway considered all the colonial coal to be of this nature; or whether his more recent researches had shown it be of a different kind.

Mr. GALLOWAY replied that he was at issue with many geologists in regard to the deposition even of English coal; and in this respect he was not alone. During recent years some eminent French mining engineers* had led a revolt against the ordinary method of explaining the presence of coal in the Coal Measures; and had declared that all the indications tended to show that coal was deposited from water like other sedimentary strata, and had not grown *in situ*. Having himself carefully investigated the subject under ground, where all the beds could be seen much better than a field geologist could see them on the surface, he had long been of the opinion which he had expressed † at various times and in his report to the government of Cape Colony, that the English and all other coal beds had been deposited in the same way as the African coal beds, and that they were all subaqueous. That other mining men of this country were of the same opinion had been shown by some recent papers which had been sent to him; only a few days ago he had received one by Mr. Hall, the President of the Manchester Geological Society, and another by Mr. A. R. Sawyer, one of the Inspectors of Mines. The question was one which, although it had not yet received much

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* Mémoire sur la formation de la Houille, par M. C. Grand' Eury. Annales des Mines, tome 1, 1882, page 99.

Études sur le terrain houiller de Commentry, par MM. Ch. Brougniart, H. Fayol, De Launay, S. Meunier, Regnault, Sauvage, et Zeiler. Bulletin de la Société de l'Industrie Minérale, tome xv, 1886.

† On the Mode of Occurrence of Coal. Transactions of the Cardiff Naturalists' Society, 1885.

(Mr. William Galloway.)
attention in this country, would probably be soon brought to the front.

Professor KENNEDY considered it would add to the value of the present discussion if some analyses were furnished of the coals to which reference had been made.

Mr. GALLOWAY said the analyses of the coals he had described were contained in his report to the Cape government, and he should be happy to furnish copies of them. (See page 128.)

The PRESIDENT said the southern portion of Africa was a region of great importance to this country, being so largely British territory; and the elucidation of the various points which had been brought out in the discussion was a valuable addition to the paper itself.

With reference to the fire-bars used for burning Welsh coal in the locomotive trials made by Mr. Galloway (page 119), he thought that the result obtained, namely 8·76 lbs. of water per lb. of coal, clearly indicated that the bars had been spaced properly for burning Welsh coal. That result was what could be got in locomotives on any English railways with the ordinary temperature of 50° Fahr. for the feed-water. The evaporation of 5·62 lbs. of water per lb. of the Indwe coal was about the average that would be got with Newcastle coal worked in a locomotive engine, even when used as large coal. Therefore there must be some elements in the Indwe coal which, were it not for the dirt, would make it much better for locomotive purposes than even English north-country coal. The lower evaporation of only 5·04 lbs. of water per lb. of the Molteno coal was exceptionally bad, and would only be expected from coal that gave off smoke like a steam-tug all the year round.

The development of the large coalfields in South Africa would of necessity be a great advantage to England. If it was not an advantage to the coal-owners in England, it would undoubtedly be an advantage to the British traders and colonists, who had at present to buy coal at about £5 per ton at Cape Town; and the ship-owners who had to

pay that price for their coal were now compelled to get more freight, in order to render their voyages profitable. The coalfields being situated within the Cape Colony, their development could not fail to prove an advantage to the empire. Moreover there could not be much doubt that, as the coal was worked inwards from the outcrop, the 29 per cent. of ash would become largely diminished. Having himself had something to do, not with working, but with using coal from the outcrops of the English coalfields, he had always found that, even when burnt in a house fire, coal from the outcrop left a large residue of ash.

As to washing the coal, he thought it would not pay to break up the coal containing 29 per cent. of ash, and then wash it and convert it into coke. It seemed doubtful to him whether it would coke at all, or whether in that respect it would not be much like the ordinary Welsh steam coal. He should not expect to get more than about 60 per cent. of coke out of it; and that coke would in his opinion be of a friable nature, as in the case of coke obtained from Welsh steam coal. The arrangement mentioned in the paper for working the locomotives with this coal he therefore thought was the only feasible one; and if Mr. Stephens could keep up steam with the present $1\frac{1}{2}$-inch spaces between the fire-bars, and not leave a fire trail behind, such as he had spoken of with the 3-inch spaces, he was going in the right direction; and the probability was that he would devise some plan by which he would succeed in reducing the $1\frac{1}{2}$-inch space still further, and get rid of the dirt before it reached the glutinous state in which it adhered to the fire-bars. Before it got vitrified he believed it would fall down, and could then be got rid of through narrower spaces.

In now moving a vote of thanks to Mr. Stephens for his paper, he would couple with it a request that in the course of a year or two, when the workings had got into the hill, and solid coal had been won at a sufficient distance from the outcrop, he would supplement the present paper by describing the further results then obtained.

Mr. WILLIAM GALLOWAY sent the following further information respecting the colonial coal, as promised in page 126.

(Mr. William Galloway.)

Analyses of Coal in Cape Colony, extracted from a report upon the Coal Deposits of the Indwe Basin and Stormberg range of mountains, by W. Galloway, Mining Engineer, 1889. Bluebook [G. 50, 89].

1. *Indwe Mine.*—Analyses of the three upper beds of the seam, by Dr. Hahn :—

Position in the seam.	Thickness of Bed.	Specific Gravity.	Volatile Constituents.	Coke.	Ash.
	Inches.		Per cent.	Per cent.	Per cent.
Top . .	11	1·26	19·57	80·43	11·08
Middle .	25	1·48	15·32	86·68	28·87
Bottom .	11	1·46	17·13	82·87	24·65

Another analysis made by Dr. Hahn of coal from this seam is as follows, but no details are given as to what part of the seam the sample was taken from :—

Specific Gravity.	Carbon. Per cent.	Hydrogen. Per cent.	Nitrogen. Per cent.	Sulphur. Per cent.	Oxygen. Per cent.	Coke. Per cent.	Ash. Per cent.
1·587	61·021	3·208	2·190	0·434	2·178	75·26	30·32

In a trial made with Indwe coal by the writer, in a small steam boiler at Molteno, the residue amounted to 37·6 per cent. In a trial made by Mr. Tilney in the furnace of a stationary boiler at East London, the residue amounted to 29 per cent.

2. *Stormberg Coal, Molteno district.*—Two analyses given in Professor Green's report, but not typical of the coal now being worked at Molteno, Cyphergat, and Fair View mines :—

Name of Farm.	Thickness of Coal.	Thickness of Shale beds.	Volatile Matter.	Coke and Ash.	Moisture.	Ash.	Sulphur.
	Ft. ins.	Ft. ins.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Van Zyls	2 1	1 2	10·31	89·69	1·13	28·80	0·76
Van Wyks	1 11½	1 2	9·22	90·78	1·77	22·34	0·97

In trials made by the writer in the furnace of the same small steam boiler at Molteno, the residue after combustion of samples of coal obtained from the three principal mines near Molteno was :— Molteno 36·6 per cent., Cyphergat 36·2 per cent., Fair View 42·6 per cent. The obvious reason why the quantity of ash is necessarily greater in practical trials than by analysis is that in the former case some of the carbon remains unconsumed, even with the most careful stoking.

Mr. STEPHENS wrote from Cape Town that since the reading of the paper he had returned from a visit to the Natal Government Railways; and having availed himself of the opportunity to inspect the mines there in operation, he could more than confirm Mr. Woodall's remarks (page 124) concerning the Natal coal, none of which resembles the Indwe or the Stormberg coal. It is almost entirely free from ingrained sand, which is the drawback to the Indwe coal; it makes steam very rapidly, and is preferred by experienced engine-drivers to the South Yorkshire coal, which it will have superseded there in a few months.

The author's visit was made for the purpose of reporting on the performance of some engines of exceptional weight and power, which are being introduced on the Natal Railways. Their unqualified success he considers is largely due to the ease with which the Natal coal maintains steam at full pressure up the longest inclines on a line with a ruling gradient of 1 in 30 and with curves freely used of 300 feet radius, notwithstanding a moderate grate-area and an ashpan much contracted by two axles underneath it.

The first mine adjoining the railway is at Elands Laagte station, 205 miles from the seaport of Durban, and the last is at Newcastle, 269 miles from Durban: in addition to which the coal seams crop out in the cuttings and watercourses for about 20 miles further along the extension of the railway now in progress from Newcastle to the Transvaal border viâ Laings Nek, where a tunnel is being made. The coalfield through which the railway runs is thus about 80 miles long; but the continuity of the coal is broken by dolerite, as described by Mr. Galloway (page 118), though not to the same extent

(Mr. Stephens.)

as in the Cape Colony. No attempt has yet been made to ascertain the width of the coalfield, the quantity of coal adjacent to the railway being to all appearance enough to supply the requirements of South Africa for many generations.

The Elands Laagte mine, from its proximity to the former terminus of the railway at Lady Smith, was the first to be extensively worked, and the early deliveries contained much shale and sulphur. It was probably from this source that the coal was supplied for the trial made by Mr. White in the dockyard at Simon's Town in 1879 (page 121).

The railway to Dundee, referred to by Mr. Woodall (page 124), has recently been opened, and the Dundee Coal Company have contracted for the Natal Railway supply. The seam worked is 4 ft. 6 ins. thick, and is perfectly clean. One of Messrs. Rennie's line of steamers, which trade from London to Natal, recently took 350 tons of this coal, and made a successful voyage; and a further order has been given. At Newcastle, 38 miles further north, there is nearly seven feet thickness of coal in three seams, with two partings of shale in which the holing is made. The trials made have shown this to be excellent steam coal, and being fairly hard it will bear transport well.

When the extensions now in progress of the Cape and Natal Railways to a point of junction in the Orange Free State are completed, the Natal coal will in all probability be used to work the upper sections of the Cape Railways; but the Indwe mine, from its proximity to the eastern system and to the projected extensions, will supply that portion of the Cape Railway system.

The author regrets that Mr. Galloway was compelled to return to England, without visiting the Natal coalfield as was originally intended.

The percentage of the volatile constituents in the coal, of which the analysis is given in page 116 of the paper, should be 13·32 he believes, as pointed out by Professor Kennedy (page 117), instead of 15·32 per cent.

ON THE MECHANICAL APPLIANCES EMPLOYED IN THE MANUFACTURE AND STORAGE OF OXYGEN.

By Mr. KENNETH S. MURRAY, of London.
Communicated through Mr. Henry Chapman.

Extraction of Oxygen from Atmosphere.—About thirty years ago the eminent French chemist Boussingault made the discovery that at a temperature of about 1,000° Fahr. the monoxide of the metal barium would absorb oxygen readily from the atmosphere, with the resulting formation of the dioxide; and that at a higher temperature of about 1,700° Fahr. the oxygen thus absorbed would be given off again, and the monoxide would apparently be restored to its original condition. Following up this discovery, Boussingault advocated the use of barium oxide for the economical preparation of oxygen on a large scale. He found however that the barium oxide gradually lost its power of recovery; and although many attempts were made by himself and others to overcome this difficulty, no one until within the last few years appears to have succeeded, and from a commercial point of view his discovery remained of little value. To the brothers Brin is due the credit of having surmounted this difficulty, and thereby paved the way for a method which within the last two years has been developed by the Brin's Oxygen Company into a reliable commercial process.

Barium Oxide.—As this is the basis on which the Brin process is founded, a brief account will be given of the way in which it is prepared and used, before going into the mechanical details of the process. Barium oxide is a mineral substance closely resembling lime in its properties. It is found combined in nature as "heavy spar" (sulphate) and "witherite" (carbonate), both of which occur most frequently in lead districts. One of the most important salts formed from the raw material is nitrate of barium BaN_2O_6, which

when in the crystalline form is found the most suitable for conversion into the barium monoxide BaO employed in the Brin process.

This oxide, which is known commercially as "baryta," is formed by decomposing the nitrate in the following manner. A series of fire-clay crucibles, each of about eight pints or one gallon capacity, are heated in a suitable open coke fire to about 1,600° Fahr. Without being removed they are gradually charged with barium nitrate, which becomes rapidly liquefied by the heat, and boils for about three hours. During this process of boiling, gases are driven off in the form of nitric oxide N_2O_2 and oxygen. When the boiling ceases, a porous mass of hard barium monoxide, equal to about half the original weight of nitrate, is left in the crucible; and this is allowed to bake for another hour, under the same conditions as to heat, in order to drive off as far as possible all remaining traces of nitrogen oxides. The crucibles are then taken out of the fire, and placed in a closed chamber, where they are allowed to cool down slowly. The baryta is afterwards removed, and stored in air-tight drums until required for use.

Baryta thus manufactured lasts a long time, and costs about 75*s*. per cwt. It is not claimed for this method of preparing the oxide that it is a cheap one. When the Brin's Oxygen Works in Horseferry Road, Westminster, were erected three and a half years ago, this particular form of baryta was not commercially known; and as, owing to its permanent nature, the quantity required for the Brin process was so limited, it was thought advisable to manufacture the oxide on the premises in the manner just described. An oxide of barium however is largely prepared in a somewhat similar manner for use in the production of the powerful bleaching agent "peroxide of hydrogen" H_2O_2; and the manufacturers of this material have already taken the matter up, with the result that lump baryta in a porous state can now be procured for about 50*s*. a cwt. As yet however this material is hardly supplied in the physical condition required for the production of oxygen, for it fails to combine in the requisite degree the qualities of porosity and hardness. In appearance a lump of baryta might be mistaken for pumice stone,

but in action it is very different. When put into water it slakes with greater rapidity than lime, and gives off much greater heat.

Production of Oxygen.—While the careful preparation of the baryta is very important, its treatment when in actual use for the production of oxygen is even more important. It was found by Messrs. Brin that, when the air was properly purified before being brought in contact with baryta thus prepared, it had little injurious effect; and also that, by peroxidising the baryta under a slight pressure, and deoxidising it under a partial vacuum, they were able to reduce the range of temperatures, and thus to avoid the high deoxidising temperature previously employed, which had acted destructively on the baryta. By the careful observance of these conditions the difficulty encountered by Boussingault and others has been practically overcome: in proof of which it may be mentioned that some of the baryta placed in the original oxygen-producer erected in Horseferry Road is still at work.

The Brin method of working was as follows. By means of a suitable pump, air was *drawn* through a purifier containing caustic lime and soda, which extracted the moisture and carbonic acid. The purified air was then delivered under a pressure of about 10 lbs. per square inch into a series of steel retorts, charged with lumps of baryta about the size of a walnut. These retorts were placed horizontally in a brick chamber, and heated to a temperature of about 1,100° Fahr. In passing through the baryta the oxygen was extracted from the air; and the nitrogen was allowed to escape again into the atmosphere through a relief valve. After the baryta had taken up all the oxygen it could—which theoretically is about 1·25 cubic foot at atmospheric pressure per lb. of baryta, though this quantity is never reached in practice—the air pump was stopped, and the heat of the retorts was increased to about 1,600° Fahr. The pump was then re-started with its action reversed, so as to draw from the retorts. At a vacuum of 26 inches of mercury or nearly 13 lbs. per square inch, the baryta yielded up the oxygen it had absorbed during the previous operation, and this oxygen was drawn off through the pump and delivered into an ordinary gas-holder

When all the oxygen had in this manner been drawn off, the pump was again stopped, the heat lowered, and the first operation repeated.

On the starting of the works in Horseferry Road, an oxygen-producing plant was erected there on these lines; but it was soon found that the process would have to be much simplified before oxygen could be obtained cheap enough for industrial applications. The injurious effect of constant expansion and contraction on the steel retorts and on the brickwork of the furnace will be readily understood, as well as the waste of time and fuel, and the constant supervision required: all of which were the necessary results of working at two temperatures. Fresh experimental work was accordingly undertaken with a view to overcoming these difficulties, and has resulted in greatly simplifying and cheapening the entire process. These results have been brought about mainly by the adoption of one temperature for both operations, by the use of vertical instead of horizontal retorts, and by the automatic working of the entire process.

In Plates 35 to 41 is illustrated a plant working on these lines, capable of producing 10,000 cubic feet of oxygen per day of 24 hours; and with the exception of the general arrangement being here slightly altered for the sake of clearness, it is in all respects similar to oxygen-producing plant recently erected.

Oxygen Producer.—The oxygen producer, shown in Figs. 1 to 3, Plates 35 to 37, consists essentially of a self-contained carbonic-oxide generator G, having a combustion chamber B on the top, which communicates on either side with chambers C containing the vertical retorts R. The carbonic-oxide generator has been specially designed by Mr. W. A. Valon, and is similar to those employed by him in the Ramsgate and other gas works; it is well adapted for use in connection with an oxygen producer, where it is a matter of great importance to be able to maintain a uniform heat of from 1,350° to 1,450° Fahr. on the retorts containing the baryta, and where it is essential to have a producer requiring little attention. The generator is charged with coke every six hours through the firing door F on the ground level, and is clinkered out every twelve

hours through the door D. A feature of these generators is that they contain no fixed fire-bars; a slight steam-jet is used, mainly to prevent the formation of clinker on the walls. Air for primary combustion of the fuel is admitted through small port-holes on each side of the clinker door D; and secondary air, for burning the carbonic oxide into carbonic acid in the combustion chamber B, is first heated by being drawn through passages Q in the walls on each side of the generator, up the back wall, as indicated by the arrows, and into the combustion chamber immediately above the opening A in the crown through which the carbonic oxide is admitted. Combustion then immediately takes place, with consequent expansion. The hot gases leave the combustion chamber through the fire-clay sleeves S, which are so arranged as to prevent the gases from impinging direct upon the retorts R. These sleeves are also fitted with fire-clay nostril pieces, which can be changed or adjusted at will through the openings in the side walls at H, thus giving a complete control over the heating of the retort chambers C. The gases are drawn off from the bottom of each chamber, as indicated by the arrows, through fire-clay sleeves, into flues L communicating with a common chimney in the back of the producer. The draught in each retort chamber C is controlled by an independent damper; and the gases can either be conducted away direct, or be drawn down into any existing flue.

Retorts.—The retorts R, Fig. 2, Plate 36, are of steel, twenty-four in number, twelve in each bay, in which they are placed vertically. They are 9 feet long in their exposed surface, 7 inches external diameter, and $\frac{1}{2}$ inch thick. Experiments are now being made with cast-iron retorts, with a view to the adoption of this material instead of steel. The retorts contain altogether about 2,100 lbs. of baryta in lumps, as already described. The weight of the retorts is taken by a cast-iron box-plate P at top, Fig. 4, Plate 38, through which they pass, and which is shielded from the action of the heat by special fire-lumps, as shown in Fig. 2. A cast-iron plate shielded in a similar way is used at the bottom of the retort chambers; but here a gland joint is formed by means of a ring of asbestos, to allow for free expansion of the retorts. The flanges and covers of the retorts, Fig. 4, Plate 38,

are of cast-iron; and the joint between them, which is found a particularly satisfactory one, is made as shown full size in section in Fig. 5, by beading the retorts at each end, recessing the covers to receive them, and placing a ring of thin sheet copper C between the faces. The cover is then screwed down, thereby moulding the copper ring to the retort end and the cover, and so forming an absolutely clean air-tight joint. The copper ring can be used over and over again.

Connecting Pipes.—The bent connecting pipes N between the retorts at the bottom, and between the retorts R and the branch cast-iron pipes E at the top, Fig. 4, Plate 38, are of weldless steel, and are connected in every case by means of a conoid-conical joint, as shown full size in section in Fig. 6. To prevent the possibility of these connecting pipes at the bottom of the retorts getting choked by small baryta lumps or dust, a cast-iron shield-plate is attached to the inside of the cover. As shown in Fig. 2, Plate 36, all the joints in connection with the bottom of the retorts are accessible through the clinkering pit of the carbonic-oxide generator. The arrangement of piping on the top of the producer and the double-acting automatic valve at W, Figs. 2 and 3, will be described later on.

Air Pump.—In small installations, such as that now described, the same pump is used for the twofold operation of pumping into and out of the retorts. It has therefore to be designed with a view to obtaining the high vacuum necessary for deoxidation. The pump shown at P in the plan, Plate 35, and in elevation in Fig. 7, Plate 39, is the type which up to the present has generally been adopted. It is manufactured by Messrs. Frank Pearn and Co. of Manchester, and is capable of creating under ordinary atmospheric conditions a vacuum of 29 inches of mercury or 14 lbs. per square inch. It is a vertical combined double-acting steam-engine and pump with two air cylinders on top, each cylinder capable of passing one cubic foot of air per revolution. For cooling these cylinders they are surrounded by tanks containing circulating water.

Purifiers.—The purifying plant, shown at U in the plan, Plate 35, and in elevation in Fig. 8, Plate 39, consists of two wrought-iron or steel cylindrical chambers of 76 cubic feet capacity each, and two cast-iron chambers of 19 cubic feet capacity each. The larger chambers are charged with quick lime CaO, and are filled only half full, in order to allow for expansion when the lime is hydrating; and the smaller ones are fully charged with caustic soda NaOH in the lump state. The purifiers are so connected by means of iron piping and valves, Plate 35, that the air to be purified passes through one or both of the lime chambers, and through only one of the soda. They are charged through a man-hole on the top, and emptied through a cleaning door at the bottom. The air passes through the purifiers on its way from the pump to the retorts, and is consequently under the same pressure in the purifiers as in the retorts. It is admitted to the purifiers at the bottom, and passes off at the top. It is first passed through one or consecutively through both of the lime purifiers, where the bulk of its carbonic acid and moisture is absorbed; and then through one soda purifier, where the remaining traces of impurity are trapped; the work done in the soda purifier is consequently very small.

The quantity of carbonic acid in the atmosphere is very slight, only about 0·04 per cent. in volume; and it varies but little under different atmospheric conditions. The quantity of moisture in the atmosphere is very changeable, and in this country may be said to vary in volume from 0·3 to 3·3 per cent.; and under average atmospheric conditions air contains in volume about 1·25 per cent. of moisture. The lime in the purifiers consequently hydrates with far greater rapidity than it carbonates. As a rough rule it may be said that one ton of quick lime will purify three million cubic feet of air. In the plant now described 86,000 cubic feet of air pass through the purifiers per day, and each purifier when charged contains about one ton of quick lime. If therefore the full efficiency were taken out of the lime, and the work done by the soda were disregarded, one lime purifier would have to be re-charged every five weeks. As complete slaking of the lime however means the formation

of a mass offering a good deal of resistance to the passage of air, in actual practice the first of the two lime purifiers is thrown out of work as soon as ever it begins to occasion a perceptible back pressure, which with the purifiers now described would be after about four weeks' working. Whilst this purifier is being re-charged, the other lime purifier and the soda purifier do the work; and when the freshly charged purifier is re-started, the order of working the lime purifiers is reversed, so that the one last charged shall always be the second in action.

The life of the caustic soda depends on the efficiency of the lime purification. One of the two soda purifiers is always in action; and as the soda has only to act the part of a catch to what has escaped the lime, it does not require to be often changed. Caustic soda has a very strong affinity for moisture and carbonic acid. As it hydrates, it liquefies; and this liquid has to be periodically drawn off through a tap T, Fig. 8, Plate 39, at the bottom of the soda purifier. The amount of liquid thus drawn off is a good indication, not only of the efficiency of the lime-purification, but also of the amount of caustic soda hydrated: the liquid soda being about double the weight of the caustic. When about half of the caustic soda has been drawn off in this way, the purifier has to be thrown out of work, and filled up again, whilst the other soda purifier is brought into action.

Cost of Purification.—Assuming that after they had done work in the purifiers the slaked lime and the liquid soda were valueless, the cost of purification per thousand cubic feet of oxygen would be about threepence. But these materials, though spent so far as complete purification of the air is concerned, are by no means valueless. The slaked lime may be used for building purposes, for which it is found as good as lime slaked in the ordinary way; and in coal gas works, where it is confidently hoped that the use of oxygen will be extensively adopted, this slaked lime has only to be taken to the ordinary lime purifiers, and there used for abstracting carbonic acid and sulphur from the coal gas in the usual way. The liquid soda, although the quantity used is very small, is disposed of for about one half the original cost of the caustic material. From these facts

it will therefore be seen that the purification of the air forms a very small item in the cost of oxygen manufacture.

The plan of purifying the air after it has passed through the pump, instead of before, has only recently been adopted. The advantages it offers over the old method are:—firstly that, as all the suction passages between the pump and the atmosphere are clear, the full quantity of air is drawn in and delivered by the pump: and secondly that traces of pump lubricants, which previously, in spite of all efforts to prevent their doing so, found their way into the baryta, are now effectually arrested by the purifiers.

Automatic Reversing Gear.—This gear, situated at G in Fig. 1, Plate 35, is shown in Figs. 9 and 10, Plate 40. It consists of four cocks, A B C D, Fig. 9, attached to a table, and geared with pistons, as shown in Fig. 10, by means of which they are actuated. Steam pressure is admitted to the cylinders E H in which the pistons work, by means of retention valves actuated at any desired moment by adjustable cams M; and the motion to rotate the cam shaft is transmitted from the air pump by means of paul and ratchet gearing. The cocks A and B and C are all three reversed simultaneously by means of the cylinder E. A is a three-way cock attached to the suction pipe of the air pump. B is a similar cock attached to the delivery pipe of the air pump. C is a two-way cock working in conjunction with A and B. D is a three-way cock similar to A and B, and worked separately by the cylinder H.

The details shown at W on the top of the furnace in Plates 36 and 37 work in connection with this automatic reversing gear, and are shown in Fig. 11, Plate 41. They consist of a double-acting automatic valve V, and a double distributing valve-box X controlled by hand. The two valves V are attached to the same vertical spindle, in such positions that when one is off its seating the other is on. They are actuated by a corrugated steel diaphragm D, which is subject to vacuum or pressure according to the position of the cocks A, B, and C. The diaphragm is about 12 inches diameter and No. 26 W. G. or 0·018 inch thick, and is corrugated cold between dies. The total fluctuation it is subject to is less

than half an inch at the centre; and as proof of its efficiency it may be mentioned that the first of these automatic valves was started seven months ago, and has been steadily at work with the same diaphragm ever since. From tests actually made, the pressure obtained on the valve by the diaphragm under a vacuum of 28 inches of mercury or about 14 lbs. per square inch is 700 lbs., the valve itself being $2\frac{1}{2}$ inches diameter. This valve is connected at one end to the pipe J, as shown in Plates 35 and 37, and at the other end to the distributing valve-box X. The latter is so arranged that, by screwing the hand wheels out or in, the direction of the air passing into the retorts may be periodically reversed, thus very much lessening the tendency the baryta has to settle when the currents of air are always in the same direction.

Cycle of Operation.—In order to convey some idea of the efficiency and cost of producing oxygen with the foregoing appliances, which constitute an existing plant for the purpose, the complete operation will now be described, assuming the air pump to be running at the rate of 60 revolutions per minute, and the automatic gear to be set so as to give four complete operations per hour, and assuming also that deoxidation has taken place and the automatic gear has just reversed all the cocks.

Air is drawn in from the atmosphere into the pump through the intake pipe I, Plate 35, and the suction cock A, Fig. 9, Plate 40, at the rate of 120 cubic feet per minute. It is compressed by the pump to about 10 lbs. per square inch, and delivered through the cock B and pipe K to the purifiers. Having passed through these, it returns by the pipe N to the automatic gear, passes through the two-way cock C into the pipe J, and thence into the automatic valve W, Fig. 11, where its pressure on the diaphragm D causes the latter to close the bottom valve V and open the top. The air being thus unable to get away through this valve passes into the distributing box X, where it is caused to enter the pipe Y, in which it is subdivided, and passes through the whole of the twenty-four retorts in pairs, passing consecutively through the two retorts in each pair, where the oxygen is absorbed by the baryta. On

leaving the retorts the nitrogen passes into the pipe Z, and through another passage in the distributing box X into the upper chamber of the automatic valve W; and the top valve V being open, it escapes thence through the release valve R into the atmosphere. It is by means of this release valve that the pressure in the retorts is controlled. When the peroxidation of the baryta has continued for $7\frac{1}{2}$ minutes, or any other desired period, the requisite cam M of the cylinder E comes round, and lifts a retention valve T, Fig. 10, which admits steam to the cylinder and thus reverses the cocks A, B, and C. By this action the purifiers are cut off *under pressure*, and are thrown out of communication with the rest of the piping. The suction cock A is thrown into communication with the retorts, and the delivery cock B with the blow-off cock D. Suction being thus created between the retorts and the pump, a vacuum is formed, which, acting on the diaphragm D of the automatic valves V, Fig. 11, reverses the position of these valves, closing the top and opening the bottom, thereby cutting off all communication from the pump to the atmosphere, and opening a communication from the tops of all the retorts to the pump, which enables the vacuum to be more rapidly created. As pure oxygen is not obtained until a vacuum of 26 inches of mercury has been created in the retorts, it is necessary to blow away the gas drawn off before this vacuum is reached. The gas is therefore discharged through the blow-off cock D into the atmosphere through the outlet Q, until the proper quality of oxygen is obtained. The cock D then reverses, and directs the oxygen into the holder H, Plate 35, the reversal being caused automatically by suitable adjustment of the cams. When this deoxidation of the baryta has continued for the desired time, the automatic gear again reverses the cocks, and the whole process is repeated indefinitely.

A governor is used in order to control the speed of the air-pump when working under the different conditions of peroxidation and deoxidation; and a safety-valve is fixed on the delivery pipe between the pump and the automatic gear, so as to prevent any excessive pressure from being thrown on the pump whilst the operations are being reversed. It will thus be seen that the reversing of the operations is entirely automatic.

Labour.—Beyond firing the boiler and the carbonic-oxide generator of the producer, and lubricating the pump and gear, nothing is left in the hands of the workman. Special labour is of course sometimes necessary: as for instance when a purifier has to be changed, or the baryta has to be taken out of the retorts to be broken up again, which latter owing to a certain amount of cohesion it is found advisable to do every three or four months. But working under ordinary conditions, with small installations such as the one described, where oxygen would be used in connection with some other process, and where steam could be taken from some existing boiler, no additional labour would be required.

Purity.—There is however another improvement of equal importance which has been effected by the automatic reversing gear, and that is in the quality of oxygen delivered to the holder. So long as the blow-off cock D was controlled by hand, the quality of oxygen could never be relied on, as any carelessness on the part of the workman might mean the admission of a quantity of air to the holder. With the automatic gear however, such a contingency is impossible; and the quality of oxygen in the holder depends entirely on the length of time allowed between the reversing of the cocks A, B, C, and of the cock D. The highest quality attainable in practice is from 97 to 98 per cent.

Cost of Production.—The cost of oxygen must always vary with the size of the plant and the conditions under which the gas is made. The quantity of ordinary gas coke used in the carbonic-oxide generator is from 12 to 15 cwts. per day; and as a rough rule, for installations ranging from 4,000 to 10,000 cubic feet per day, the pumping power required is one IHP per thousand cubic feet of oxygen, decreasing of course as the plant increases in size. The actual cost of production, allowing for depreciation of retorts and baryta, probably ranges from two shillings per thousand cubic feet in coal gas works to seven shillings in works specially erected for the production of oxygen only, where additional charges have to be made for labour and rent.

Although, in a process which has already shown itself capable of so much improvement, further improvements may yet be realised in the shape of a more perfect extraction of the oxygen from the atmosphere, there can be little doubt that the essential difficulties have now been overcome, and that a cheap and simple mechanical process for the manufacture of oxygen is at the command of engineers and chemists, who will not be long in finding applications for it.

In retail business with the supply of cheap oxygen the demand has been daily increasing. For while during 1887 Brin's Oxygen Co. sold from their works in Horseferry Road no more than 142,000 cubic feet of oxygen for lime-light and other purposes, the quantity they sold during 1889 amounted to just 1,000,000 cubic feet, notwithstanding that the Manchester Oxygen Co. which has recently been started has within the last two months taken over the trade of the whole of the north of England.

High-Pressure Storage Cylinders. — All this gas has been compressed and delivered to consumers in high-pressure cylinders, which are charged to 120 atmospheres, and vary in capacity at that pressure from 3 to 225 cubic feet, ranging from 3 inches to 5½ inches outside diameter. As shown in Fig. 12, Plate 41, they are spherical at one end, and have a neck formed on the other, into which is screwed and sweated a high-pressure valve, shown in section in Fig. 13. The material used in their construction is mild steel, and they are either solid-drawn or lap-welded. Up to 40 cubic feet capacity the cylinders used by Brin's Oxygen Co. are solid-drawn and seamless; the larger sizes are lap-welded.

The seamless vessels are made by Messrs. Taunton, Delmard, Lane and Co., of Birmingham, who, the author understands, now make them up to 9 inches diameter and 5 feet long. They are made by taking a thick circular flat slab of steel, which by repeated heating and pressing in a hydraulic machine is moulded into a tube with a spherically closed end. The final processes of drawing are carried out with the steel in a cold condition, and annealing intervenes between each cold process. When the requisite size is obtained, the open end of the tube is nozzled or swaged in,

so as to form the neck. This repeated process of drawing acts beneficially on the strength and rigidity of the metal. The thickness of seamless vessels is rather less than that of lap-welded cylinders of the same diameter, and varies from 1-8th inch for vessels of 3 inches diameter to 5-16ths inch for those of 9 inches diameter. The ordinary hydraulic test applied is 2 tons per square inch. The trade in these cylinders has sprung into existence very rapidly, and Brin's Oxygen Co. now have many thousands of them passing through their hands.

Compressors.—The compressors employed for charging the cylinders are of a three-stage type. They were originally designed by Mr. Howard Lane of Messrs. Taunton, Delmard, Lane and Co., and have since undergone many improvements and alterations. In those now employed, the first cylinder is double-acting, being $5\frac{1}{2}$ inches diameter with a stroke of 9 inches. The second and third cylinders are single-acting, having a stroke of 9 inches, and are $2\frac{3}{4}$ inches and $1\frac{3}{8}$ inches diameter respectively, being fitted with ordinary hydraulic rams instead of pistons. Gas enters the first cylinder direct from the holder, and is compressed in three stages until it leaves the third cylinder, from which it enters the vessel to be charged. The gland joints are formed with ordinary hydraulic leathers, together with a small quantity of water, which is admitted with the gas, and acts also as the cylinder lubricant. The water after it leaves the compressor is separated from the gas by gravity, and periodically drawn from a receiver. The three compressing cylinders, in order to be kept cool, are surrounded by a tank of cold water, which is always circulating.

The compressor is coupled to the crank-shaft of a 10 H.P. vertical engine, by which it is driven, the engine being fixed on the same foundation as the compressor. At a speed of 90 revolutions per minute this compressor will compress one thousand cubic feet of gas per hour to a pressure of 120 atmospheres.

Pressure Regulator.—For utilising the compressed gas in the storage vessels, its pressure has to be reduced from the very high

pressure at which it has been stored, to the low pressure at which it is generally required to be used, probably not exceeding a few inches of water. For this purpose the pressure regulator shown in Fig. 15, Plate 41, is attached to the high-pressure valve, Fig. 13, from which the high-pressure gas is admitted at A to the regulating chamber C, whence it flows out through the delivery pipe P at the reduced pressure required. The chamber C is enclosed by a piece of corrugated india-rubber tubing capable of elongation, and is closed at the outer end by the diaphragm D loaded by the spring S. A system of levers L, on the principle of a lazy tongs, is centred at its outer end in the diaphragm D, and at its inner end in the base of the chamber, in which is the seating of the conical plug or inlet valve I. Each of the innermost levers is prolonged to form an eccentric projecting on the opposite side of the centre; and the two eccentrics work in a bridle on the top of the inlet valve I. The opening of the inlet valve by the pressure of the gas contracts the levers and draws the diaphragm D inwards; but the pressure of the expanded gas on the large area of the diaphragm pushes it outwards and extends the levers, thereby closing the inlet valve by the action of the eccentrics. The extent of opening of the inlet valve depends upon the quantity of gas that is being drawn off through the delivery pipe P; and its reduced pressure is regulated by the strength of the spring S loading the diaphragm D. The lighter the spring, the lower is the pressure to which the gas is reduced; the size of spring shown in Fig. 15 is suitable for giving the gas a pressure of about 12 inches of water.

For using the gas direct from the storage vessel without the pressure regulator, a nozzle like that shown in Figs. 16 and 17, Plate 41, is attached to the high-pressure valve, Fig. 13; and a flexible tube is secured on the grooved end of the nozzle, for leading the gas to any point desired.

Conclusion.—The compressor completes the mechanical appliances in connection with an oxygen factory. If the author has succeeded in showing that the Brin process is a simple mechanical method of manufacturing oxygen, the object of this paper will have been

attained. For information respecting the industrial applications already established of this gas, reference may be made to a paper read by Mr. W. A. Valon before the Gas Institute at their annual meeting last year (Transactions 1889, page 41), and also to a paper read by the company's chemist, Dr. Thorne, before the Society of Chemical Industry about a year ago (Journal 1889, page 82).

Discussion.

Mr MURRAY exhibited specimens of the baryta or barium monoxide, taken from the retorts in which it had already been for some time in use; and also of the nitrate of barium from which it had been prepared for the purpose. He showed also samples of the copper rings forming the joint of the retort covers; and specimens of the corrugated steel diaphragms actuating the automatic valves of the reversing gear; also of the solid-drawn seamless storage cylinders, and of the flat slabs of steel from which they were made; and of the valves by which the cylinder necks were closed.

In connection with the paper now read, the Members were invited to visit Brin's Oxygen Works, Horseferry Road, Westminster, on the three days of the present meeting and on the following morning, for the purpose of witnessing the process of manufacture and inspecting the machinery employed.

Mr. JOSEPH ADAMSON said that, having carried out some small contracts for the works in Westminster ever since they began, he had been much struck at their commencement by the large amount of money that was being spent upon them, with the view as he then fancied of making a show in London of what could be done with oxygen; and he had thought that, if they were wanted to be well carried out, it would have been better to establish them somewhere in the provinces. But as the erection of the works progressed, it

became evident to him that practical utility was being considered more than mere appearance; and he accordingly became more and more interested. Each time that he had visited the works, and especially in the visit he had made to them this very day, he had been more than ever struck by observing how much simpler the process had become. In another way also he felt an interest in these works, because, in the face of the present facilities for obtaining technical instruction during the evenings, the difficulty was to get men or boys or young apprentices to stick to their work; and in the boiler shop there was consequently great difficulty in getting men to understand welding properly, which he thought was the most skilled piece of work in mechanical engineering. Now that he had heard of the cost at which oxygen could be produced, he was more than ever convinced that it would ultimately become, what he had from the first anticipated it would become, one of the principal agents in welding, flanging, melting, bleaching, and other processes. If at the special oxygen works described in the paper oxygen could now be made for seven shillings per thousand cubic feet, he had no doubt that, as the result of further experiments, it would ultimately be made for two shillings, as was already being done by Mr. Valon at the Ramsgate gas works; and it would then become commonly used in all large works, like bleaching works, and in boiler shops, in which he was himself most interested. That there was a great future for oxygen gas he was fully assured by what he had seen, although when it first came out it had appeared to be simply a luxury or a plaything. Already at Ramsgate it had been proved by Mr. Valon that it was an essential means for making good hydro-carbon gas for lighting; and he had no doubt that in a short time the experiments which were being carried on there and at the works in Westminster would result in oxygen being used in many engineering establishments.

Mr. ROBERT A. HADFIELD said that two years ago he had been very courteously shown over Brin's Oxygen Works, and had been pleased to see that the manufacture of oxygen had been made a practical and commercial success. From what he had then learned,

(Mr. Robert A. Hadfield.)

he felt sure that there must have been serious difficulties to contend with; and it was a great credit to all concerned that they had succeeded in working out this process. There was a great field he thought for the use of oxygen in metallurgical processes; and he agreed with the previous speaker that it might be used with considerable advantage for many engineering and manufacturing purposes.

With reference to the moisture in the air, which was stated in page 137 to rise to as much as 3·3 per cent. in volume, he should like to know how much that percentage was actually reduced by passing the air through the lime purifier, and whether the remaining moisture was entirely removed by afterwards passing it through the soda.

Professor ALEXANDER B. W. KENNEDY, Vice-President, asked whether it was to be understood that the great improvement brought about in enabling both the oxidation and the de-oxidation of the baryta to take place at the same temperature was due to the difference of pressure employed: the oxidation being carried on under a pressure of 10 lbs. per square inch above the atmosphere, and the de-oxidation under a pressure of about 13 lbs. per square inch below the atmosphere. It seemed to himself that from a commercial point of view this was the key to the success now realised, by enabling the retorts to be worked constantly at one temperature, instead of requiring the temperature to be altered at regularly recurring intervals and to the extent of as much as 500° Fahr.

Mr. EDWARD B. MARTEN, Member of Council, said that a few days ago he had seen this process exhibited in miniature by means of a working model at a conversazione at the Midland Institute in Birmingham. Having now had the opportunity of seeing the process carried out on the large scale at the works, which he had to-day had the pleasure of visiting, he had been astonished to find that there should have arisen such a demand for the oxygen as to make it worth while to put up such extensive works for its manufacture; and he should be glad therefore if a few instances were given of the applications that were now being made of the oxygen. Its

application to boiler-making, mentioned by Mr. Adamson (page 147), was one which he could himself well understand and appreciate; but there might be many others that had not occurred to the Members.

In regard to the automatic reversing gear, he should like to know whether he understood aright that it was set to reverse its action at certain intervals, which were a matter of judgment on the part of the manager who set it going, and beyond the control of the workmen. Also at the moment of reversal, when the air-pump began to exhaust from the retorts, was it arranged by calculation beforehand how long the gas drawn off while the full vacuum was being formed should be blown away to waste, and was the blow-off stopped automatically? or did an attendant watch the process, and close the blow-off cock at the right time?

The cylindrical vessels that held the compressed oxygen, without which its manufacture would be useless, constituted in his opinion a very interesting part of the work. A great deal of skill he thought must have been applied to making those vessels, which were carried about he presumed with absolute safety, for he had not heard that one had ever burst. No doubt processes such as this of oxygen manufacture depended upon what had been done before in other directions also; for unless there had been the means of procuring such vessels, large works like these would have been utterly useless, because they could not have distributed the oxygen produced. He had seen at the works the compressing pump used for filling the vessels, and as stated in the paper (page 144) it had three compressing cylinders enclosed in water; and he gathered that in the first cylinder the gas was compressed to a certain amount of pressure, still further in the second, and to the final pressure in the third. Was it always compressed in the third cylinder to the same final pressure of 120 atmospheres mentioned in the paper? or was the ultimate pressure varied according to the size of the vessel employed for the storage of the compressed gas?

Mr. MURRAY replied that the oxygen was always compressed to the same final pressure of 120 atmospheres in charging the storage vessels; and the compression was effected in three successive stages

(Mr. Murray.)

in the three cylinders of the compressing pump, the final pressure being attained in the third cylinder.

Mr. CHARLES E. COWPER asked how long the storage vessels would retain the gas under the pressure of 120 atmospheres; because under so high a pressure he should imagine that there would be a constant leakage going on, though perhaps very slight, through the metal itself. He further asked whether at the Brin works vessels were charged with hydrogen also; and if so, what precautions were taken to distinguish between the vessels containing the different gases. It was customary he believed to paint the vessels of different colours, in order to distinguish those used for oxygen, and those used for hydrogen. He had been told of an accident which had occurred, not through defect of the vessel itself, but through carelessness in charging one gas into a vessel already partly charged with the other, thereby forming an explosive mixture.

Mr. MARTEN mentioned that he had seen at the works a number of the vessels bearing large labels marked with the different names.

Mr. WILLIAM SCHÖNHEYDER said it appeared to him, from what he had been able to see of the process as carried on at the works which he had visited, that there must be a considerable amount of waste, and that the cost of producing the oxygen must consequently be greater than it need be: although at the same time it might be that it was less wasteful and much cheaper than any other mode, and therefore it might pay well. In the first place the waste gases or products of combustion which escaped after heating the retorts must be passing off at a considerable temperature, 1,000° Fahr. or more; and their escape at that high temperature into the atmosphere or into the chimney would be attended with a considerable loss of heat. Further there was the pumping of the cold air into the red-hot retorts, which were at the temperature of 1,000°, or whatever it might be. The nitrogen of the air was discharged into the atmosphere, and the oxygen was afterwards exhausted by the pump; so that the whole of the heat which had been put into that air was wasted again, instead

of being caught as it might be in some regenerator. There was yet a further loss, which, as it appeared to him, must take place more or less in the nitrogen that escaped through the discharge valve into the atmosphere. It was said to be nitrogen that escaped; but was it all nitrogen? Was all the oxygen really extracted out of the air? Did not the baryta become so fully charged with oxygen, especially towards the last part of the process, that it could not take up more, so that a large portion escaped with the nitrogen through the discharge valve? Then again, when the reversal took place, he understood that pure oxygen was not obtained until after the pump had been worked long enough to produce the full vacuum in the retorts; and in the meantime a certain quantity of gas was blown away to waste, until it was found that really pure oxygen was being drawn off. It seemed to him therefore that the process, although a great improvement on what had been hitherto done, must still be more or less wasteful in these directions.

Mr. Bernard Dawson, having been concerned in laying out the works, could see from the drawings that considerable alterations and improvements had since been made upon the original design. He should like to know whether anything had been done towards using oxygen for glazing pottery, for which purpose it seemed well suited; for some pottery during glazing had to be exposed in ovens or kilns to a high temperature of an oxidising kind.

Dr. L. T. Thorne, having been connected with the oxygen works for some time as chemist, said there was no doubt that the high-pressure storage vessels had already been of great importance in relation to the demand for oxygen, and would continue to be so. For the distribution of oxygen on the small or retail scale, they were indispensable; and the strength of the vessels and the security of the valves were of course points of vital importance. These high-pressure vessels however were essential only where small quantities had to be dealt with. Where large quantities had to be dealt with, as for instance in gas-works and in many other manufacturing processes, the gas-maker or the manufacturer requiring to use oxygen

(Dr. L. T. Thorne.)

would make it on his own premises, and would then need only to run it at once into an ordinary gas-holder, and store it there without any compression, for use as required. This was now being done in Germany, and also at Ramsgate, where works had been put up; and other works were in course of erection, where oxygen would be made and used on the premises, and where the compression of the gas would therefore be needless.

The accident mentioned (page 150) as having occurred to one of the storage vessels had been due to carelessness in putting oxygen into a cylinder containing coal gas. Such a risk must be avoided by all possible means; and accordingly it had now been decided that at the oxygen works all the high-pressure vessels which were to be used for coal gas or hydrogen should be made with left-handed threads, so that they could not through any inadvertence be connected with the compressor, the high-pressure testing apparatus, or other fittings used for oxygen. Therefore that accidental mistake could not occur in future.

Waste of heat no doubt occurred in many parts of the process; but it was waste which was more or less unavoidable. In all manufacturing processes there was waste; and even with the waste that was at present incurred, the oxygen could be produced at the low cost mentioned in the paper.

For welding he thought there was no doubt that oxygen would come into use largely; and he was also convinced that it would play an important part in metallurgical work in the future, especially in the reduction of what were generally known as refractory ores. Attempts to apply it for this purpose were already being made on a small scale in the way of experiment; and several smelters who were dealing with refractory ores were only waiting the final results of some of the furnaces that were being put up, in order themselves to make experiments in that direction on a large scale.

As to the moisture in the atmosphere (page 148), the 3·3 per cent. mentioned in the paper was given as the maximum of moisture ever present in this country; and it was only in tropical countries that this percentage was ever exceeded. It was indeed an exceptional amount to be present in the atmosphere of the British Isles, the

average being from 1 to 1¼ per cent. The average however could only be spoken of very generally, because it differed so much in different localities. Attempts had been made to get something like an approximate average, but they were all more or less fallacious: the average in London would differ from the average at Greenwich, which was one of the points chosen by the meteorological council; and this again would differ from that at Marlborough, and other places in the kingdom. But roughly, for commercial purposes, it might be taken that from 1 to 1¼ per cent. by volume was something like the average moisture over a range of years. Naturally the lime and soda purifiers did not take out absolutely all the moisture from the air, but they did take out by far the larger proportion; and he believed that what remained did not exceed a few hundredths of one per cent. or even less: so that for practical purposes it might be considered that all the moisture was taken out. There was an interesting point however in connection with this small residue, namely that it showed how useful in some cases a slight imperfection of this kind might really be. As mentioned in the paper, the original discovery of the property of barium monoxide to absorb additional oxygen and form the peroxide, and then to give up again the additional oxygen and be reduced to the monoxide, had been made by Boussingault. This chemist at once thought that here was the means of obtaining oxygen economically on a large scale, and that the process would be valuable commercially; but when he came to work it out, he found that after being used a few times the barium monoxide gradually lost the power of absorbing additional oxygen; and although a great number of experiments had been made, failure had for a time always resulted. The subsequent solution of this difficulty was no doubt due to the proper physical condition of the baryta, to the lower temperature that was sufficient when a vacuum was used, and to other causes. One of these causes, he was convinced from the general results, although he had not completed his own experiments to prove it, was the minute percentage of moisture still left in the air after it had passed through the purifiers. Boussingault, in his experiments on a few litres of gas, had purified his air from moisture almost absolutely; whereas the trace of moisture now left in it had

(Dr. L. T. Thorne.)

an appreciable effect, he believed, in keeping the surface of the baryta in a good condition for the absorption of the additional oxygen.

As to the constant temperature of the retorts (page 148), the means of working them at a constant temperature was the employment of the difference of pressure. It had long been known that, in any re-actions where one solid and one gas combined to form a solid, and where a solid compound was decomposed into a gaseous and a solid constituent, increase of pressure aided the formation of the compound, and decrease of pressure aided the decomposition of the compound into its solid and gaseous constituents. But that practical use could be made of this fact for obtaining at one constant temperature such a formation and decomposition as were shown to take place in the process now actually carried on was hardly anticipated; and it was only after careful experiments had been made that this was found to be the case. A dull red heat, or about 1,100° Fahr., was most advantageous for the formation of barium peroxide; and a bright red heat, or about 1,600° Fahr., was most favourable for decomposing barium peroxide into oxygen and barium monoxide. But if a temperature were taken of about 1,350° Fahr., and an increase of pressure were employed of about 10 lbs. per square inch, it was found that a certain amount of barium monoxide could be converted into the peroxide; and then by reversing the pressure and forming a vacuum of something like 13 lbs. per square inch, a considerable part of that peroxide could be decomposed into oxygen and barium monoxide. Theoretically 1 lb. of barium monoxide ought to absorb 1·25 cubic foot of oxygen to form the peroxide; and of course in the subsequent decomposition the same quantity, 1·25 cubic foot of oxygen, ought to be obtained again when the peroxide was reduced to the monoxide. In practice, owing to the imperfect porosity of the barium oxide, the process, even when carried on with the change of temperature, had never been worked successfully to the full extent of the theoretical quantity of oxygen; but as a rule only about half that proportion, namely about 0·60 or 0·70 cubic foot of oxygen, had been obtained per lb. of barium oxide. In now working with one constant temperature they only succeeded in getting a much smaller quantity, namely about one-sixth of the former quantity, or only about 0·10 cubic foot of

oxygen per lb. of baryta. But where the present advantage came in was that, in the old process where changes of temperature took place, the operation even when hurried could never be completed much under three hours, and it generally took four hours, so that no more than from six to eight operations could be got in a day; whereas now, with the constant temperature, the whole operation of oxidation and deoxidation could be accomplished in from ten to fifteen minutes, and thus from 100 to 140 operations could be carried out in a day. While therefore per operation there was a considerable loss in the quantity of oxygen obtained, yet the aggregate make per day now reached from three to four times as much as it did formerly.

The use of oxygen for glazing pottery (page 151) had been talked about; but he did not know of any actual experiments having hitherto been made in that direction. In the allied process however of glass blowing and glass working it was being used. The oxy-coal-gas flame instead of the ordinary coal-gas blow-pipe was being used by glass-blowers, and they found a great advantage in it. They were able by this means to manipulate lead glass without any danger of causing the reduction of the lead and the consequent discoloration of the glass. They were also enabled to manipulate hard glass, such as "combustion" and "gauge" glass, with almost as much ease as hitherto they had been able to manipulate the soft lead glass.

Among the more important uses already made of oxygen (page 148), one of the first to mention was its application to the purification of coal gas. As was well known, oxide of iron was used for the purpose of removing the sulphur from ordinary illuminating gas; and the spent oxide was afterwards revivified several times by exposure to the air, until at last it could no longer be so restored, and became useless. Experiments on the use of oxygen to revivify the oxide of iron had been made on a large scale at the gas works at Blackburn by Mr. Ogden, and at Westgate by Mr. Valon, and in both cases with successful results. The amount of sulphur that was precipitated in the oxide of iron purifier was much larger than formerly; and consequently a given quantity of iron oxide did its work for a much longer period. While Mr. Valon was experimenting in this matter, he found also that the same advantage was

(Dr. L. T. Thorne.)

obtained by the use of oxygen in lime purification. By adding a small proportion of oxygen to the crude coal gas before it entered the purifier—somewhere about 0·10 cubic foot of oxygen for every 100 grains of sulphuretted hydrogen contained in 100 cubic feet of the crude coal gas—the action of the lime purifiers was rendered much more efficient, the sulphur compounds in the resultant illuminating gas were reduced to a much lower point than hitherto, and the use of auxiliary oxide of iron purifiers became unnecessary. The lime did its work both more efficiently and for a longer period, so that less lime was used; consequently a saving of labour was effected, and better purification was produced. Those experiments had been made at first on a small scale with oxygen sent to Westgate in high-pressure storage cylinders, and later with the summer make of oxygen at Ramsgate by means of a small oxygen producer put up there for the occasion. The results in both cases had been so satisfactory that the Ramsgate corporation had decided to take up the process for a permanency; and permanent plant for producing oxygen enough to treat the whole of the Ramsgate supply had recently been put up, and was now nearly ready for use, and it was hoped to have it in full work in a month's time, or less. The total quantity of sulphur remaining in lighting gas after having been purified in this way was found not to exceed 8 grains per 100 cubic feet. The sulphur caught in the lime purifiers remained fixed in the lime, partly indeed as free sulphur, and was not carried forward by the gas passing through—as it was ordinarily when the lime became saturated with carbonic acid; and the duration of the lime was nearly doubled. Moreover when at last the lime became spent, it had not the foul smell of the gasworks' "blue billy," but was almost devoid of odour, and therefore no nuisance to the neighbourhood of the gas works.

Besides the advantages of improved purification, of reduction in the quantity of lime and consequently of labour, and the avoidance of auxiliary oxide of iron purifiers, an increase had also been noticed in the illuminating power of the lighting gas produced. In many gas works it had hitherto been the practice to add air in small quantities to the crude lighting gas, in order thereby to cause revivification of the oxide of iron in the purifiers; and in some cases air had also been

used in conjunction with the lime purification. But where air was so used, the residual nitrogen was of course left in the lighting gas, and being an inactive diluent it diminished the illuminating power of the gas. When pure oxygen was used for these same purposes, instead of air, no inactive diluent was introduced, but only a small surplus of oxygen passed on into the lighting gas. This had been found by Mr. Valon to cause an increase in the illuminating power of the gas; and thus, instead of the decrease experienced under the ordinary conditions, a decided increase was obtained; and there was no doubt that, the higher the illuminating power of the lighting gas made, the greater was the increase caused in its illuminating power by the presence of the small quantity of oxygen. The proportion of oxygen present must of course be only small; if it exceeded a certain amount, then a diminution in illuminating power would at once commence. The maximum point of advantage differed in different cases, being larger as the illuminating power of the gas was higher.

Experiments had also been made on a large scale with regard to the use of oxygen for bleaching purposes. To a great extent at all events bleaching was an oxidising process, and in the natural bleaching field—on the sward in the sunshine—oxygen played a most important part. Hitherto however it had been found that the direct use of oxygen on a large scale had been ineffectual; when it was attempted to bleach with free oxygen a naturally coloured substance, such as grass or linen, whether at a moderately high temperature or under pressure or in conjunction with water, the effect was very slight indeed. But it had now been found that, when the oxygen was used in conjunction with bleaching powder, the effect became very marked. In the laboratory the effect was such that sometimes a saving of 50 per cent. of bleaching powder might be realised by the use of oxygen. On a large scale, dealing with some tons of material at a time, the saving of bleaching powder had varied from 25 to 35 per cent.; and this saving had been effected at the cost of about 200 cubic feet of oxygen per ton of raw material dealt with, such as straw or esparto grass. The experiments had been made mainly in connection with paper works; and also, though not on so large a scale, in connection

(Dr. L. T. Thorne.)
with the manufacture of jute goods. The cost of the 200 cubic feet of oxygen was much less than of the amount of bleaching powder saved; consequently a considerable saving was effected. The bleaching effect in these cases he thought was due to an action of the intermediate products. The free oxygen was not active enough in its ordinary gaseous state to start the oxidation of the colouring matters; but if the oxidation was started by the bleaching powder—that is by what was the true oxidising agent in the use of bleaching powder, namely the nascent oxygen liberated by the action of the chlorine contained in the powder—then the free oxygen could carry it on.

Experiments were also in course of progress, and had already got beyond the strictly experimental stage, for the use of pure oxygen in the oxidation of oils for making varnishes, and for thickening oils to such a consistency as was required in the manufacture of linoleum. Here it was found that by using pure oxygen the same amount of oxidation could be effected at or below the temperature of boiling water, and in from three to six hours, as was at present effected by treatment at a much higher temperature for a much longer period of time. In these cases the advantage was not only in economy, but also in avoidance of danger, because one of the great difficulties to contend with in the treatment of oils at present was the danger from fire in the boiling of the oils.

Experiments had also been carried out with regard to the use of oxygen in the rapid production of vinegar; and it had been found that by using a small proportion of oxygen a great saving of time could be effected. Many other applications of oxygen had been suggested, and more or less experimented upon. One was the manufacture in Germany of sulphuric anhydride, which would probably develop into a large business; it already called for a considerable consumption of oxygen. Producers were also about to be put up for the use of oxygen in connection with the preparation of natural dyes. Thus there was no doubt that the applications of oxygen were beginning to be developed, but only beginning; for it was only recently, since there had been the means of supplying oxygen at a price which brought it within the range of practical

commercial work, that manufacturers had really begun to think of the applications to which it might be put.

Sir James N. Douglass, Vice-President, said that, considering the work in which he was engaged, it might readily be imagined how great was his own interest in the subject under discussion, in connection with the aid which might be expected to be derived from the oxygen in the production of flame light. He recollected the late Mr. Goldsworthy Gurney being much interested in the question, and proposing to Faraday to throw a jet of oxygen into the flame light produced by fatty oils; and after making experiments Faraday had recommended the Trinity House to make a practical trial at Orford Ness lighthouse, on the coast of Suffolk, with the flame of a four-wick concentric burner in the focus of a lighthouse apparatus. The results of those experiments had been very important indeed. With the same sectional area of the flames as that of the four-concentric-wick oil-lamp, the relative intensity of the lights was as two and a half to one. The matter would have been followed up, but the oxygen made from native oxide of manganese was too dear, costing about £8 per thousand cubic feet; it could not compete commercially with the oil that was then being used. He was therefore delighted to hear of the success that had attended the Brin process in cheapening the production of oxygen so far that at coal gas works it could now be made at from two shillings to three shillings per thousand cubic feet. The experiments going on at Ramsgate he hoped would be a success. There was plenty of room for improvement in lighting gas; and if the oxygen process were a commercial success, a purer and certainly a better light would be obtained. Having had the pleasure of going over the oxygen works on the previous day with the author, who had been kind enough to show him all the details of the manufacture, he had been much pleased with the mechanical perfection of all the appliances. It was not often that he had seen works of that class carried on with such mechanical perfection; and it was pleasing to find that this manufacture was going on in London almost at their own doors. The three-stage compressor driven by a 10-H.P. engine at a speed of 90 revolutions

(Sir James N. Douglass.)

per minute seemed to him to be working very efficiently to compress 1,000 cubic feet of gas per hour to the pressure of 120 atmospheres. He had himself been using air compressors for several years, and he knew of none which exceeded that amount of work.

Mr. ARTHUR PAGET, Vice-President, asked whether he was right in supposing that the price of the oxygen was from two shillings to seven shillings per thousand cubic feet delivered at the oxygen works.

Mr. MURRAY explained that that was not the case. Two shillings per thousand cubic feet was the cost of oxygen manufactured at coal-gas works, where there were exceptional facilities for its manufacture, and where it was stored on the spot without compression, and was used as made. In the oxygen works in Westminster, and other similar works where oxygen was specially manufactured, and where there were consequently additional charges to be made, seven shillings per thousand cubic feet was about the cost of the oxygen compressed in the storage vessels and delivered at the works.

Mr. PAGET said it was evident that a large percentage of the cost of the oxygen as at present used must be in the compressing, the use of the storage vessels, and the transport; and therefore when the process was carried on, not in one or two works, but, as there was no doubt it would be before long, in scores of works all over the country, it seemed reasonable to anticipate that the real cost to the consumer would probably be reduced to about one quarter of the present cost. In regard to preserving only the greater portion of the oxygen that was extracted from the air by this process, and having to blow off the rest to waste (page 151), he did not see why the latter should be said to go to waste. If a certain percentage were got at a certain cost per thousand cubic feet, and if it cost more per thousand cubic feet to get a larger percentage, it seemed to him folly to try to get more, and wisdom to take what could be got cheaply and to leave the rest. As to the whole process being spoken of as wasteful in other respects, he thought that wasteful was almost always a comparative expression; and in comparison with any other mode of obtaining

oxygen the Brin process he thought was not wasteful. Mechanical engineers would recollect that one of the main objects which kept them provided with work, and for which they claimed credit, was the production of power from the combustion of coal. In that case if as much as even 25 per cent. of the heat got out of the coal could be turned into power, it would be thought to be a very good result. Therefore the process described in the paper, looking at it comparatively, did not seem to him to be wasteful. There appeared to him to be a great future for the applications of oxygen. One for which he had heard it was used was for converting new whiskey with a raw bad flavour into mature and well flavoured whiskey, by passing oxygen through it, whereby the fusel oil, which so deteriorated the whiskey and took ordinarily twenty years and upwards to get rid of, could be got rid of in about as many hours.

Mr. MURRAY in reply said the figures given of the work done by the compressor (page 160) were based not upon calculation but upon actual measurement. Already four of these compressors had been made, the results of which were proved to be the same as stated. The first cylinder of the compressor was double-acting, being fitted with a piston, which enabled more gas to be got through this compressor than he thought was the case with any others used for similar purposes.

With regard to the cost of the oxygen, Mr. Paget was perfectly correct (page 160) in assuming that the compressing of the oxygen increased the cost materially. In works specially erected for the manufacture of oxygen, where the gas always cost most, the compressing certainly added about 50 per cent. to the cost.

Oxygen had been used for maturing whiskey (page 161); but the effect produced he believed was mainly a matter of opinion. Most of those who had tasted oxygenated whiskey reported favourably, and considered it good. Oxygen was also used to produce a similar effect in wines and brandy.

In regard to the length of time that the oxygen remained in the storage vessels (page 150), there had been a good deal of trouble in that matter; but the trouble had been occasioned almost exclusively

(Mr. Murray.)

by the valves, and not by the steel vessels. It had been found that the valves were porous; and several metals had been tried, before a satisfactory valve had been arrived at. The valves now used, of which samples were exhibited, had been found most satisfactory. Vessels fitted with these valves would retain oxygen for many months at the pressure at which they were charged, namely 120 atmospheres.

The PRESIDENT asked what metal the valves were made of, and whether it was run more than once.

Mr. MURRAY replied that the metal was bronze, and that it was run three times, which he supposed was the secret of its being found so satisfactory. Great care had also to be taken in the machining of the valves. Oxygen had been sent in these bottles to Australia, and on arriving there they had been found to be still fully charged, none of the oxygen having been lost on the voyage.

In order to avoid the possibility of oxygen and hydrogen being accidentally mixed (page 150), every precaution that could be thought of was being taken. Hitherto the oxygen cylinders had been painted black, and the hydrogen cylinders red; but as an additional precaution, as already mentioned by Dr. Thorne (page 152), all the valves of the hydrogen cylinders were now being made with left-hand threads, and the regulators and gauges and all the connections that were used for hydrogen were also being made with left-hand threads: so that it would be impossible for the two gases to get mixed accidentally.

The action of the automatic gear (page 149) was entirely beyond the control of the workmen. The motion of the gear was taken from the charging and discharging air-pump; and the cams were properly set for working the retention valves of each reversing cylinder. One cylinder E, Fig. 9, Plate 40, reversed three of the four cocks; and the other cylinder H reversed the fourth, which was the gas-delivery cock D. The cam of the first cylinder E which reversed the three cocks was set at about twenty revolutions of the air-pump in advance of the cam of the cylinder H which reversed the

gas-delivery cock D. In this way the three cocks were first reversed; and then the air in the pipes, together with the impure oxygen which was drawn off before the requisite vacuum in the retorts was obtained, was blown off into the atmosphere; and by the time that the pure oxygen was beginning to be given off, the cam of the cylinder H came round and lifted the retention valve, admitting steam to the cylinder H, which thereupon reversed the cock D, and directed the oxygen into the holder. To get the purest oxygen this operation need not last much more than a quarter of a minute. The loss of time entailed (page 151) was very slight, and with such a process must always exist. It was minimised as much as possible by cutting off the purifiers, by shortening the piping between the retorts and the pump, and by doing away as far as practicable with all clearance space.

The PRESIDENT regarded this paper as one of the most interesting that had been read, and it certainly had elicited a highly interesting discussion. Perhaps the first idea that suggested itself as to the use of oxygen gas was its employment in the lime light for theatrical and other purposes, to which its application had been known for some years past; but something more had now been arrived at. It seemed to him however to be still only in its infancy; and there was an extensive field for the use of oxygen in its pure state, now that it could be produced in such large quantities, as he had himself seen when visiting the works on the previous day. For welding purposes, to which Mr. Adamson had referred, it was highly important; because it must be borne in mind that the oxygen to produce the welding flame was clean, and was not contaminated with any noxious compounds; the welding could therefore be done with a pure flame, and the heat could be intensified to any extent requisite. With regard to this application of the oxygen therefore he was fully satisfied of the advantages which would be derived from its use. He had now great pleasure in proposing the vote of thanks to the author, which he knew the Members would heartily accord; and as they had been kindly invited to go over the works on the following morning, he should

(The President.)

advise all who were either mechanically or chemically so inclined to avail themselves of the opportunity.

Mr. WILLIAM A. VALON, having been prevented from attending the meeting, sent the following remarks:—

The application of pure oxygen to aid the purification of coal gas has met with complete success at the Ramsgate Corporation Gas Works, as also experimentally at Westgate-on-Sea; and from the want felt for oxygen in this purification, it is rapidly extending to other works. The method pursued is very simple. The oxygen having been made and stored in a holder, as described in the paper, the outlet of the holder is attached to a proportional meter, which answers the double purpose of regulating as well as registering the quantity of oxygen passing into the crude coal gas. The drum of this meter has a capacity equal to one-hundredth part of the capacity of the drum of the station meter, which registers the whole of the coal gas made at the works; and the drum of the proportional meter is driven through geared wheels from the drum of the station meter at the same number of revolutions per minute. Hence the proportional meter abstracts from the oxygen holder a quantity of oxygen equal to one per cent. of the coal gas that is passing at the time through the station meter. By changing the gearing, the percentage of oxygen can be increased or decreased with precision within certain limits; and by these means the required percentage of oxygen is passed into the crude coal gas with a steady and uniform flow. The point at which it is thought most desirable to admit the oxygen to the coal gas is the inlet to the exhauster, because the agitation caused by the quick revolution of the exhauster blade assists the rapid diffusion of the oxygen; it may however be admitted at any point before the crude gas reaches the purifying boxes.

The percentage of oxygen required is governed by the sulphuretted hydrogen H_2S and the sulphur in other forms CS_2, which are contained in the crude gas. In practice it has been found that 0·10 cubic foot of pure oxygen is sufficient for every 100 grains of sulphuretted hydrogen present in 100 cubic feet of coal gas. It is

also found that with this percentage of oxygen the illuminating power is increased to the extent of at least two candles beyond what is obtained from the admixture of 1·00 per cent. of air with the gas, instead of the 0·10 per cent. of oxygen. The quantity of oxygen required depends also partly on the speed at which the gas is passing through the purifiers. The required percentage holds good, whether lime or oxide of iron is used in the purifiers. With the latter material, the boxes once charged will not require renewing until the oxide has taken up about 75 per cent. of its own weight in sulphur; and the ordinary sized purifiers would therefore last considerably over two years before requiring to be re-charged. Whilst oxide of iron however removes sulphuretted hydrogen readily, it has no influence on sulphur in any other form. As the sulphur is required to be kept down within the maximum limit of 20 grains per hundred cubic feet of the purified gas, special treatment is necessary for arresting this impurity, and lime is generally used for the purpose; and it is here that oxygen plays an important part as an auxiliary to good and economical purification.

The ordinary process of lime purification needs separate boxes for the complete removal of carbonic acid CO_2 from the gas, before proceeding to extract the sulphur. The gas is passed secondly through boxes containing sulphide of calcium (foul lime), where the bisulphide of carbon CS_2 is arrested; and finally the sulphuretted hydrogen is removed by passing the gas through boxes containing oxide of iron. The working of the process involves constant watching and anxiety; added to which the periodical removal of the foul lime, however carefully carried out, is a great nuisance to the neighbourhood.

By the mixture of the above small percentage of pure oxygen with the crude gas, the difficulties of lime purification disappear. The action of the oxygen on the lime is to retain the sulphur and the carbonic acid in the same box, a result hitherto considered unattainable. The carbonic acid seems to have little or no power to drive the sulphur forward in the presence of this small quantity of oxygen; and the process of complete purification goes on as a nearly simultaneous operation. The lime when saturated for carbonic acid contains from 13 to 20 per cent. of sulphur in various forms. This

(Mr. William A. Valon.)

renders unnecessary the use of boxes charged with oxide of iron, except in cases where the gas contains large quantities of the sulphur impurity, and where consequently it may be desirable to use oxide; but in such cases these boxes will remain closed for years before needing to be re-charged with fresh material.

By the oxygen process the separation of as much of the sulphur impurity as it is possible in practice to eliminate is accomplished in the most simple manner: that is to say, sulphur in all forms is kept uniformly and with certainty down to 8 grains per 100 cubic feet of gas; and although this point is reached occasionally with the sulphide of calcium process, the result is never certain, and the sulphur will rise frequently in a few hours to 20 grains or more, without any apparent cause, or at any rate without any cause that can be guarded against.

With the oxygen process the carbonic acid test is the only one that needs watching. The lime boxes are used in turn, in the same order as when sulphuretted hydrogen is being removed by oxide of iron; that is, the lime is worked in successive boxes until the carbonic acid at the outlet of any box is equal to that at the inlet of the same box; then that box is thrown out of action, and another substituted in its place.

The space or area required for purification is much reduced when oxygen is used. Lime will do twice the work, and is rendered doubly active by the use of oxygen; while the action of oxide of iron is greatly quickened thereby. In ordinary purification, by the expenditure of much labour in removing and spreading, and with an extended area, oxide of iron will take up from 50 to 55 per cent. of its own weight of sulphur; by the use of oxygen, with one half the area and without any labour, it will take up from 75 to 80 per cent.

The advantages of using oxygen in the purification of coal gas may therefore be summarized as follows: simplicity in working, economy in lime and oxide of iron, economy in labour, economy in space, higher illuminating power, and complete immunity from nuisance.

MEMOIRS.

Daniel Adamson was born at Shildon, in the county of Durham, on 30th April 1820; and could just remember being present at the opening in 1825 of the Stockton and Darlington Railway, the first commercial railway in the world. Leaving school in 1833 on his thirteenth birthday, he became four days later a pupil of Timothy Hackworth, of the Stockton and Darlington Railway, the earliest railway engineer and locomotive superintendent in England or the world: under whose pupilage he remained till 1841. He afterwards served under Mr. Hackworth's successor, Mr. William Bouch, as draughtsman and superintendent of stationary engines at the Shildon Engine Works, until in 1847 he became general manager of the works at the age of twenty-seven. This position he resigned in 1849, in order to become general manager of the Heaton Foundry, Stockport, where he remained for the next two years. In 1851 he commenced business on his own account as a manufacturing engineer, ironfounder, and boiler-maker, at Newton Wood and Newton Moor Iron Works, near Manchester, where he carried on an increasing business for twenty-one years, until the works became too small. In 1872 he erected new and more commodious engineering works at Hyde Junction, Dukinfield, near Manchester, which subsequently were greatly enlarged, and were fitted with the most modern machinery; they now cover nearly four acres, and employ over six hundred men, whose wages amount to £40,000 per annum.

His engineering career was distinguished by his introduction of several valuable inventions. He it was who in 1852 first introduced the flange-seam flues for enabling Cornish and Lancashire boilers to carry higher steam-pressure; and at the time when the results were published of Sir William Fairbairn's investigations with regard to the strength of boiler flues to resist collapse, he had already made as many as 180 boilers with these sectional flues, all of which were carrying the highest steam-pressure of any till then manufactured.

This flange-seam, known by his name, is now generally used by the best boiler-makers, not only throughout England but in Europe and America.

He was perhaps best known as the pioneer in introducing steel for engineering purposes in 1857 and 1858, more particularly in the construction of locomotive and other boilers; and, although for many years he was alone in using it, he persevered in its employment, until now the application of steel has completely superseded that of iron in his own works, and has generally come more and more into favour. Up to the present time his firm has made considerably over 3,000 steel boilers for working at pressures varying from 50 to 250 lbs. per square inch; and it is now much more practicable to carry a pressure of 100 lbs. per square inch in large boilers than it was in his early manhood to carry only 10 lbs. In 1858 he also applied hydraulic power to lifting jacks and to the riveting of metallic structures.

During 1861 and 1862 he designed a triple-expansion compound engine. In connection with compound engines he also introduced improvements in the superheating of the steam in its passage between the cylinders. In 1873 he built and worked a quadruple-expansion compound engine for economising steam and saving fuel. To these practical efforts in the direction of higher steam-pressure and greater expansion may probably be ascribed much of the success attending the adoption of the triple-expansion marine engine, which is now such a marked feature of marine engineering.

In the manufacture of steam boilers he introduced in 1862 the practice of drilling instead of punching the rivet holes, and of drilling them through the two plates together, after the plates had been bent into position. This method of drilling the holes is now universally demanded in the practice of boiler-making.

Besides manufacturing all classes of heavy machinery, as well as general millwright's work and hydraulic machinery, he also constructed several special American inventions, including engines fitted with the Wheelock automatic expansion gear; and his engine with this gear gained the gold medal at the Inventions Exhibition in London in 1885. In 1878 he introduced a gas producer in conjunction with boiler furnaces; also machinery for testing the

tensile strength of metals, and at his works are testing machines of from 30 to 2,000 tons power, for testing the breaking strength of bridge iron, and for other purposes; in 1881 appliances for the consolidation and working of metals; in 1887 improvements in the flues and shells of boilers, and in the machinery employed for making them; and a labour-saving arrangement by which as many as twelve tools can be worked simultaneously on a 60-ton bed. At the Edinburgh International Exhibition in 1886 his horizontal engine, which had been used for driving the electric-lighting machinery, was awarded the gold medal. The "Charter" gas engine was also manufactured by him.

About 1861 he became largely interested in cotton spinning, and was chairman of the Newton Moor Cotton Spinning Company from its formation in 1862, their two mills containing 107,000 spindles. In 1863–4 he erected, as engineer and part owner, the Yorkshire Steel and Iron Works at Penistone, the first works in this country to depend entirely on the manufacture of Bessemer steel on a large scale; he supplied the whole works with engine and boiler power and complete Bessemer steel plant. Shortly afterwards these works were sold at a considerable profit to Messrs. Charles Cammell and Co., of Sheffield. In 1864–5 he erected blast-furnaces for himself at Frodingham, which were subsequently formed into the North Lincolnshire Iron Company, with himself as chairman. These are among the largest of the blast-furnaces erected in that district, and have been attended with a high measure of prosperity. In 1863 he made improvements in converters for Bessemer steel, and in blast engines for blowing Bessemer vessels; these engines he fitted with the piston air-valves and solid air-pistons, having metallic surfaces without packing-rings, which have since been almost universally adopted. He made and supplied blast-furnace and Bessemer blowing engines, together with the requisite plant, for many of the largest iron and steel works in this country and abroad; and at the present time his own works consume about 80 tons of steel per week for engineering purposes.

It was more particularly as a manufacturer of steel boilers that he made his mark. This he did in three different ways, each of

them sufficiently notable, namely:—firstly, by the early adoption of Bessemer and open-hearth steel, instead of iron; secondly, by recognising the importance of using high-pressure steam generally, and thereby economising fuel; and thirdly, by drilling the rivet holes, instead of punching them as had previously been the custom.

He was a Member of this Institution from 1859, a Member of Council from 1876, and a Vice-President from 1885. He was a regular attendant at the meetings, and took the keenest interest in the Proceedings. He was also a Member of the Iron and Steel Institute from its formation, and was elected President in 1887, presiding over the London meeting for the first time in May of that year. At the May meeting held in London in 1888, the gold medal of the Institute was presented to him for his investigations into the properties of iron and steel, and as the pioneer in the use of steel for steam boilers and for general engineering purposes. The papers which he read before the Institute included one in 1875 on high-pressure steam generally, and its application to quadruple engines; another at the Paris meeting in 1878, on the mechanical and other properties of iron and mild steel; and his last, read while he was President in 1888, on a horizontal compound-lever testing machine of 15,000 powers, with further recording lever of 150,000 powers. He was also a Member of the Institution of Civil Engineers. As President of the North Staffordshire Institute of Mechanical and Mining Engineers, he read to that body a paper on some of the properties of puddled iron, ingot iron, and steel, for constructive purposes. He was a Member of the Cleveland Institution of Engineers, the British Iron Trades Association, the Railway and Canal Traders' Association, the Geological Society of London, the Society of Arts, the Manchester Geographical Society, the Manchester Literary and Philosophical Society, the Manchester Geological Society, the Dukinfield Library and Astley Institute, and others. He was also a director of the Manchester Chamber of Commerce, the chief promoter and first chairman of the Manchester Ship Canal, and a magistrate for the county of Chester and the city of Manchester.

He possessed a fuller knowledge of the science and practice of metallurgy than most men of his time. Only last summer he was invited by the Italian government to report upon the capabilities of the iron mines of the island of Elba, and left England for that purpose in September 1889, calling at Paris, Leghorn, Florence, and Rome. The work itself occupied him about six weeks.

He is probably one of the most notable examples which this country has produced of what can be done by indomitable perseverance and tenacity of purpose, combined with a ready judgment. His death took place at his residence, The Towers, Didsbury, near Manchester, on 13th January 1890, in the seventieth year of his age, after an illness of several weeks consequent upon a disorder of the stomach, which had developed itself rapidly after his return from Italy at the end of October 1889.

DAVID BANDERALI was born in Paris on 18th January 1836, and entered the École Polytechnique in 1854, and the École des Mines, as an outside pupil, in 1856. On finishing his studies he began active work as a professor, and gave lessons in England to the younger members of a royal household. In December 1859 he entered the service of the Northern Railway of France, where he was successively locomotive inspector at Amiens and assistant carriage superintendent in January 1866, until in 1873 he was placed in charge of the central locomotive and carriage department. This position with slight changes of title he occupied up to the time of his death. In the Exhibitions of 1878, 1881 (electrical), and 1889, he served as a member of committees and juries, and rendered services at international conferences, and for the military organisation of the French railways; and he was commandant of the fifth section of French branch railways. In 1882 he received the Cross of the Legion of Honour. After a short illness he died on 30th March 1890, at the age of fifty-four. He became a Member of this Institution in 1879.

JOHN CLARKE, senior partner in the firm of Messrs. Hudswell Clarke and Co., of Hunslet, Leeds, was born at Allendale,

Northumberland, on 6th February 1825. He served his apprenticeship to Messrs. Hawthorn, Forth Banks, Newcastle-on-Tyne; and in 1847 went to Leeds, where he entered the employment of Messrs. Kitson Thompson and Hewitson, Airedale Foundry. He was appointed their manager in 1851, and continued so until 1860, when he commenced business on his own account in partnership with the late Mr. Hudswell, establishing the Railway Foundry in Jack Lane, Hunslet. Although in delicate health for some years past, he was able to give attention to business up to the day preceding his death, which occurred on 8th February 1890, at the age of sixty-five. He became a Member of this Institution in 1865.

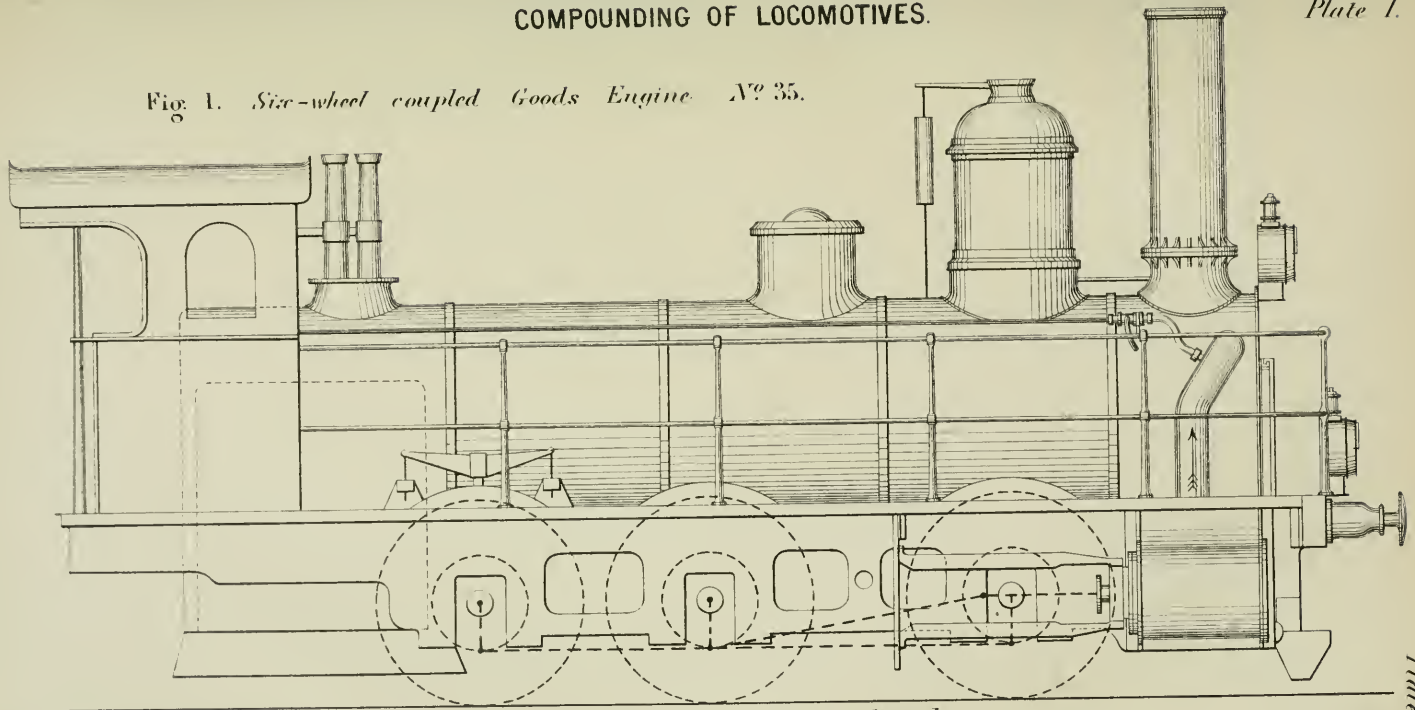
ALFRED C. HILL was born at Ebbw Vale on 17th October 1835, being the youngest child of Mr. Samuel Hill, who held the position of engineer at the Ebbw Vale Iron Works for about twenty years. In 1836 the family removed to Llanhylleth, a few miles down the valley, and in 1839 to Risca, near Newport. Here they remained for some years, but eventually went to reside at Newport, where Mr. Hill entered on his professional career at the Uskside Iron Works. Here he became acquainted with the late Mr. Thomas James, afterwards of the Redcar Iron Works. In 1854 Mr. James became engaged as manager, and Mr. Hill as mechanical draughtsman, at the South Bank Iron Works, Yorkshire, belonging to Sir Bernhard Samuelson, Bart., M.P. He afterwards went as head draughtsman to Messrs. Bolckow and Vaughan, at their Middlesbrough works, and upon the accidental death of Mr. Williamson in October 1856 was appointed engineer. In 1858 he went to Witton Park, and erected a blast-furnace there; after which he was given the management of the blast-furnaces and the rolling mills. Whilst at Witton Park he invented with Mr. William Morgan a fettling for puddling furnaces, consisting of a mixture of coal tar with coke; but the prejudices of the puddlers prevented it from being successful. In 1863 he erected the Clay Lane blast-furnaces, which when completed he managed as well as the South Bank furnaces. He also acted as engineer for the Bishop Auckland Iron Works. In 1870 he was engaged to build the Lackenby furnaces. These he managed till

1876, when he again undertook the management of the Clay Lane and South Bank furnaces. The South Bank works being eventually sold, he continued to manage the Clay Lane furnaces up to the time of his death, which took place there on 27th October 1889 at the age of fifty-four. In addition to his regular employment, he acted as consulting engineer for many other works, including those of Messrs. Newton Chambers and Co., Thorncliffe Iron Works, Sheffield; the Awsworth Iron Works and the Stanton Iron Works, near Nottingham; Messrs. Thomas Richardson and Sons, West Hartlepool Iron Works; the Outwood Iron Works, near Manchester; the Yniscedwyn Iron Works, Yniscedwyn; the South Cleveland Iron Works, Glaisdale; the West Marsh Iron Works, Middlesbrough; Messrs. Thomas Allan and Sons, Stockton-on-Tees; and the Russia Copper Co. He was also consulting engineer for the following mines and collieries:—Kilton, Craghall, Liverton, West Hunwick, and Pelaw Main. He was occasionally consulted by the late Mr. Edward Williams, of Middlesbrough, and by Messrs. Palmers' Shipbuilding and Iron Co., Jarrow. He became a Member of this Institution in 1871, and in that year gave a paper on the compound-cylinder blowing engines at the Lackenby Iron Works, and in 1872 a further paper on the working of these engines and of the Howard boilers supplying them with steam. He was also a Member of the Iron and Steel Institute, and a Past-President of the Cleveland Institution of Engineers.

THOMAS ROBSON was born at Rainton in the county of Durham on 2nd December 1836. He was a pupil of the late Mr. Thomas Emerson Forster, a mining engineer of considerable practice in the counties of Durham and Northumberland, under whom he subsequently held appointments at Framwellgate Moor Colliery in Durham, and at Wylam Colliery in Northumberland. About twenty-six years ago he was appointed mining engineer for the Earl of Durham's Lumley Collieries, which position he held up to the time of his death. About 1873 he opened out a colliery in Queen's County, Ireland, which gave employment to a number of persons, thereby adding materially to the prosperity of the district in which the colliery was situated, and considerably alleviating the depression which at that

time was much felt in agricultural pursuits. His abilities as a mining engineer were of the highest order; and, though not specially identified with any invention connected with his calling, he was regarded as being in the front rank of his profession. He was for many years chairman of the Chester-le-Street Board of Guardians, and was also a member of the Durham County Council. He died at Lumley Thicks on 17th January 1890, of cerebral hemorrhage, at the age of fifty-three. He became a Member of this Institution in 1866.

Fig. 1. *Six-wheel coupled Goods Engine No 35.*



(Mechanical Engineers 1890)

Scale 1/50th

Inches 12 6 0 — 5 — 10 — 15 — 20 — Feet 25

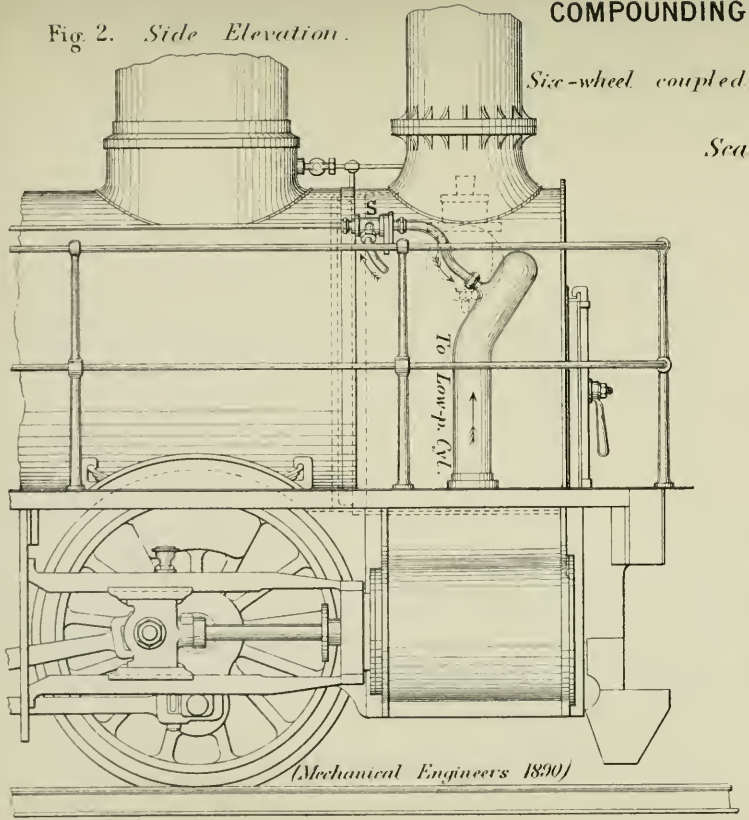
Plate 1.

COMPOUNDING OF LOCOMOTIVES.

Fig. 2. *Side Elevation.*

Six-wheel coupled Goods Engine N° 35.

Scale $\frac{1}{30}$th



(Mechanical Engineers 1890)

Fig. 3.

Transverse Section through Smoke-box.

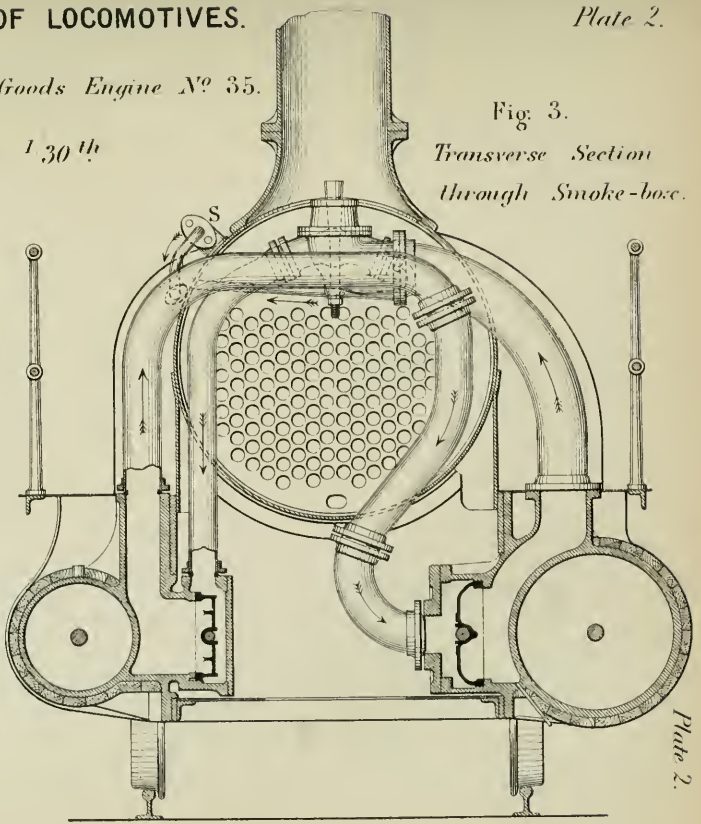
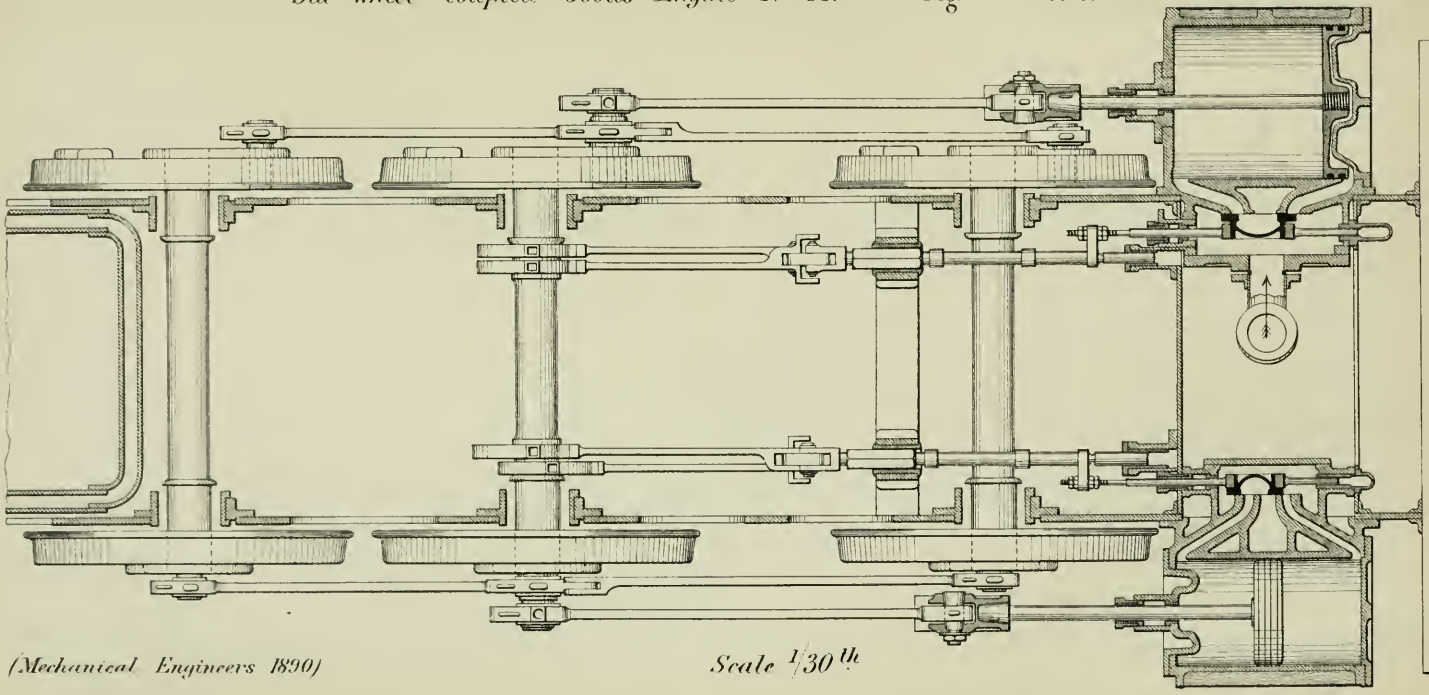


Plate 2.

Six-wheel coupled Goods Engine N° 35. Fig. 4. *Plan.*



(Mechanical Engineers 1890) *Scale 1/30th*

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 *Feet.*

Plate 3.

Fig. 5. *Passenger Engine N° 110 with four wheels coupled.*

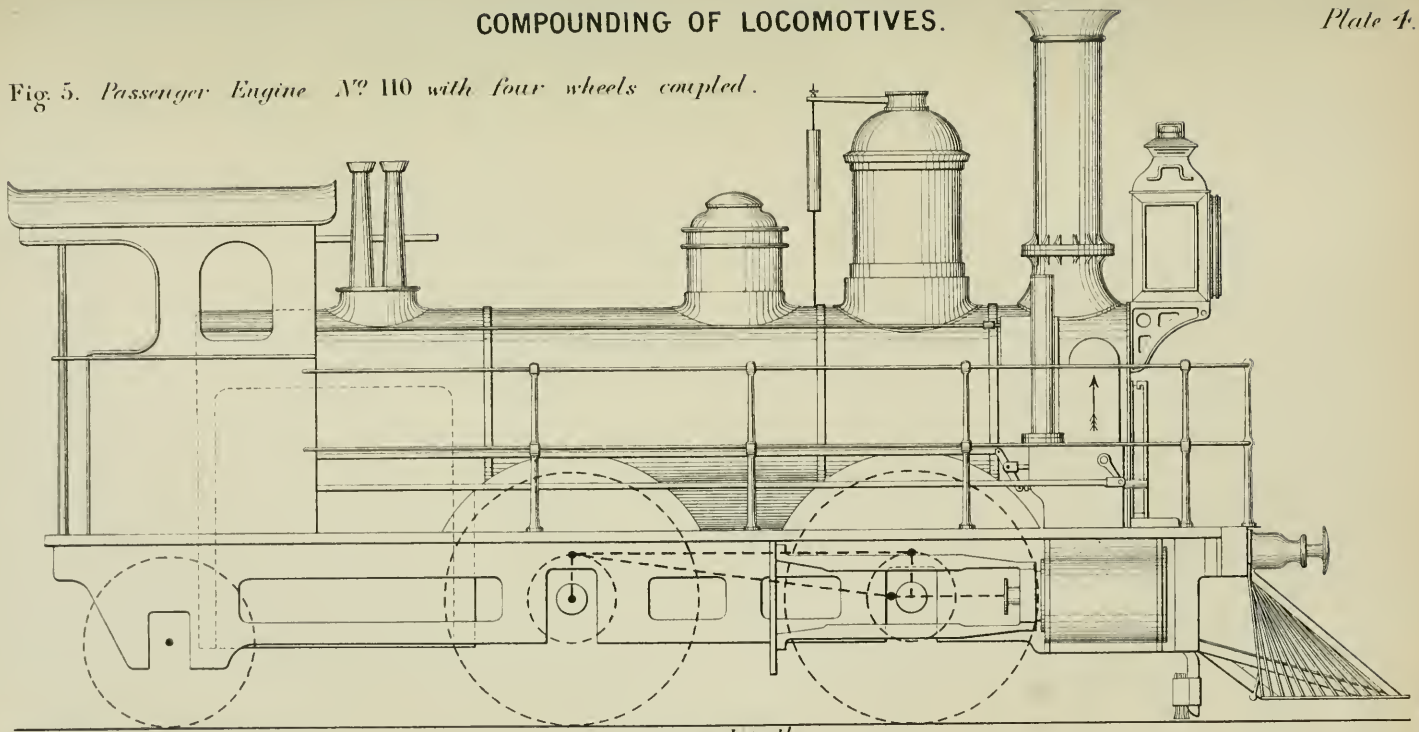


Plate 4.

Fig. 6. *Side Elevation.*

COMPOUNDING OF LOCOMOTIVES.

Passenger Engine No 110
with four wheels coupled.

Scale 1/30th

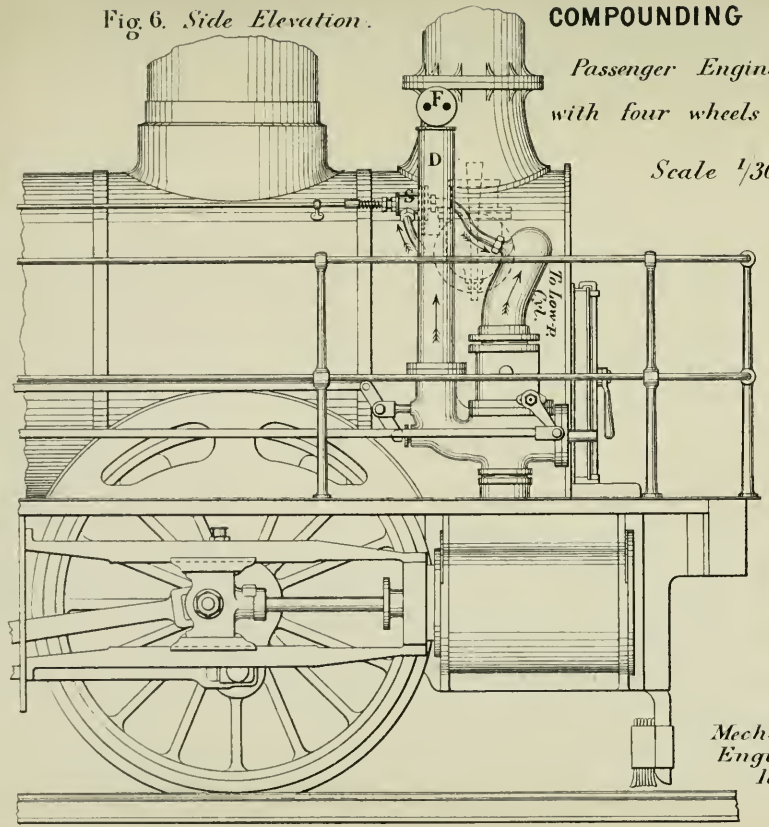
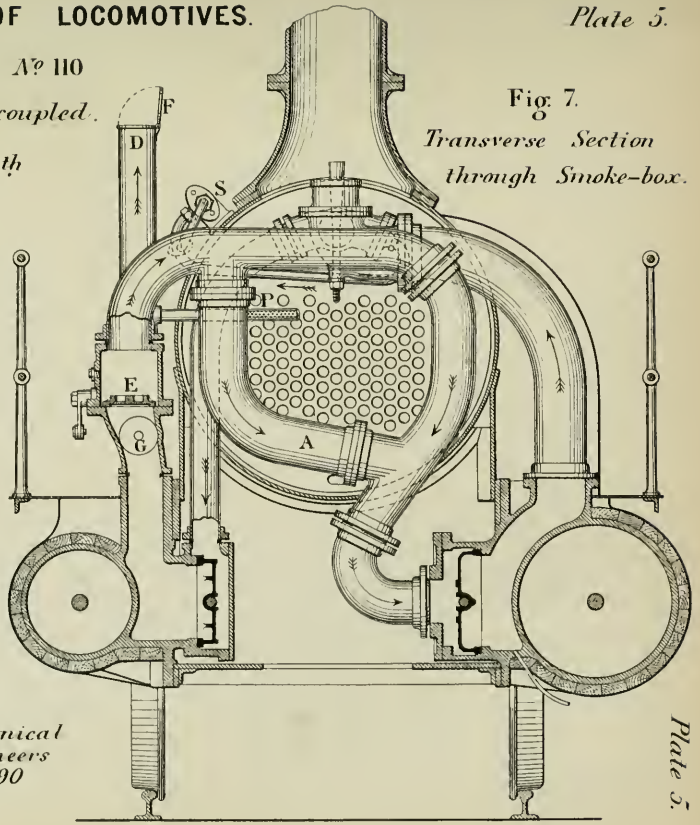


Fig. 7.
Transverse Section through Smoke-box.



Mechanical Engineers 1890

Plate 5.

Passenger Engine № 110 with four wheels coupled.

Fig. 8. *Plan.*

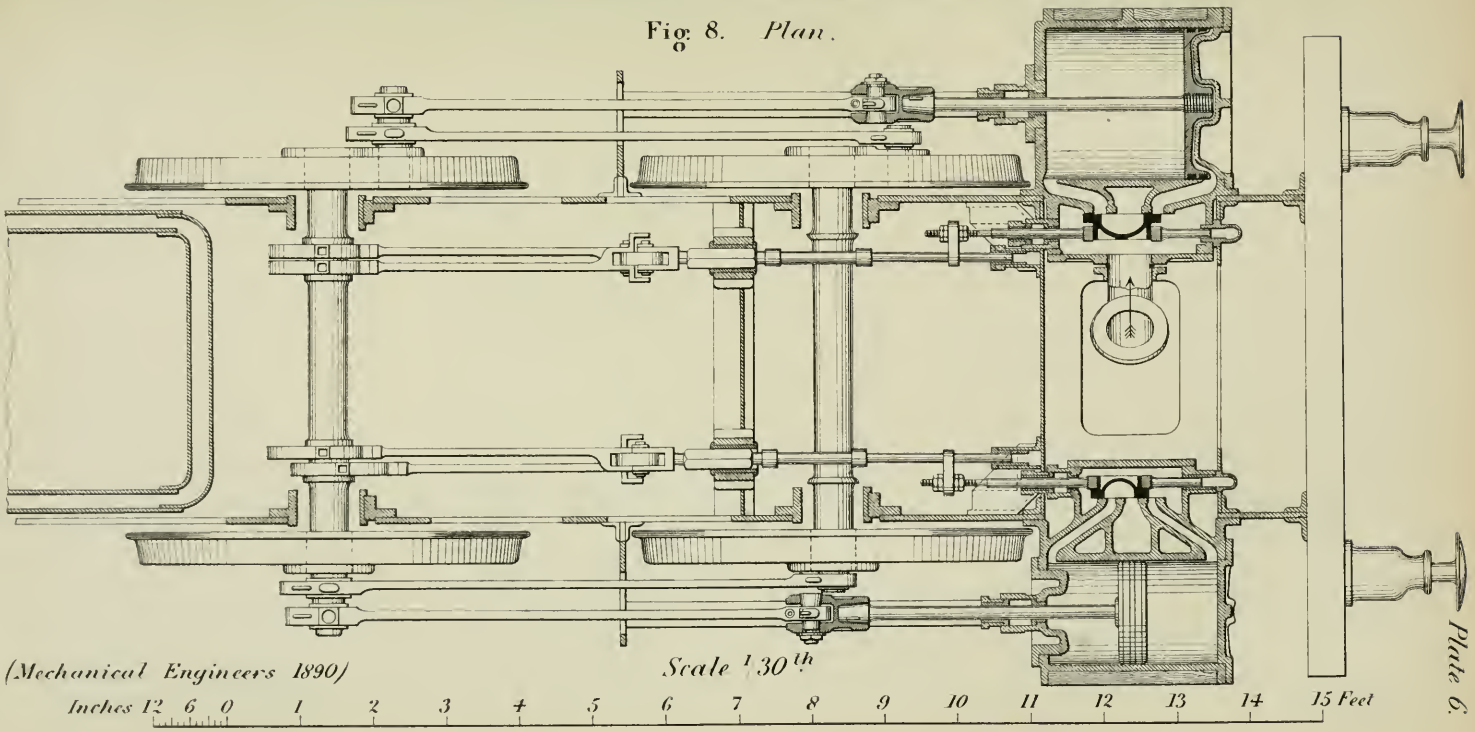


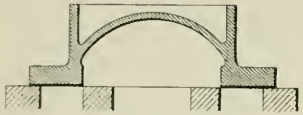
Plate 6.

Steam-ports and Slide-valves.

Compound Goods Engine № 35.

Fig. 9. *High-Pressure.*

Fig. 10. *Low-Pressure.*



Scale 1/10th

Compound Goods Engine № 40.

Fig. 11. *High-Pressure.*

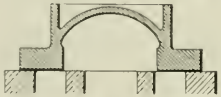


Fig. 12. *Low-Pressure.*

(Mechanical Engineers 1890)

COMPOUNDING OF LOCOMOTIVES.

Plate 7.

Interchanging and Intercepting Valves.

Fig. 14. *Plan.*

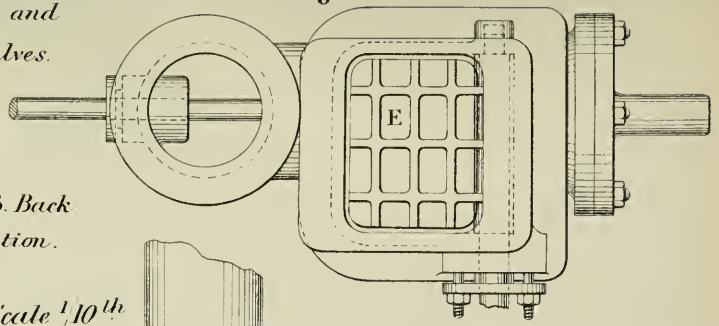
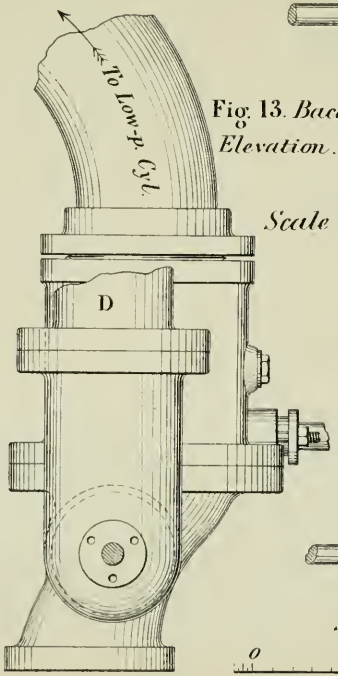
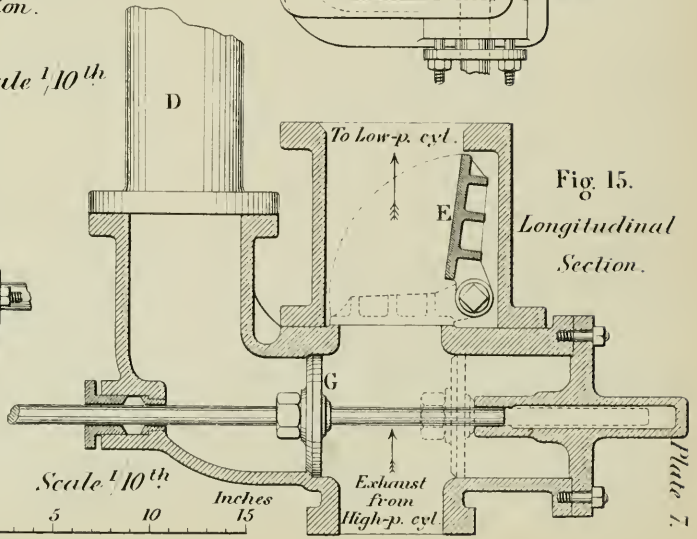


Fig. 13. *Back Elevation.*



Scale 1/10th

Fig. 15. *Longitudinal Section.*



Scale 1/10th

Plate 7.

Relieved High-Pressure Slide-valve.

Fig. 16. *Back-plate.*

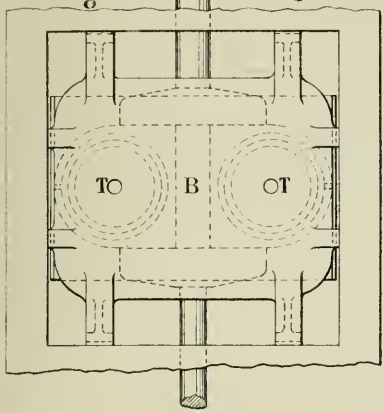


Fig. 18. *Back of Valve.*

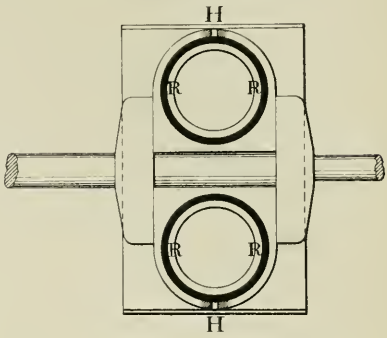


Fig. 17. *Transverse Section.*

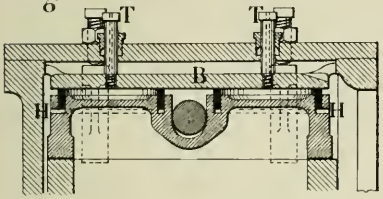
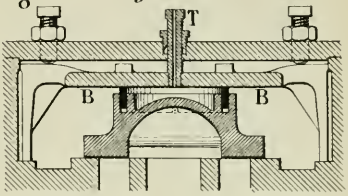


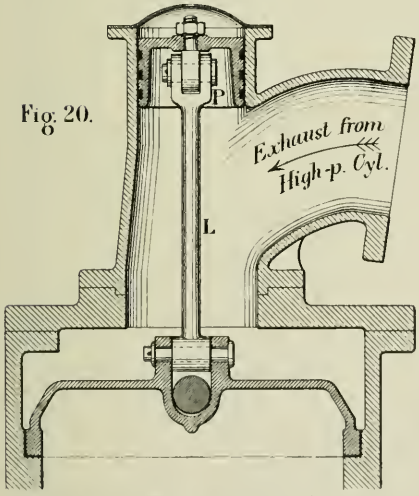
Fig. 19. *Longitudinal Section.*



Relieved Low-Pressure Slide-valve.

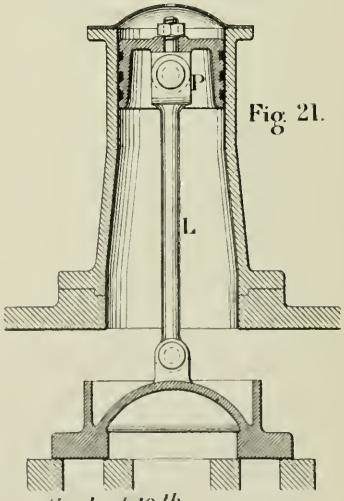
Transverse Section.

Fig. 20.



Longitudinal Section.

Fig. 21.



(Mechanical Engineers 1890)

Scale 1/10th

0 5 10 15 20 25 Inches

Indicator of Reversing Gear. *Scale 1/8th*

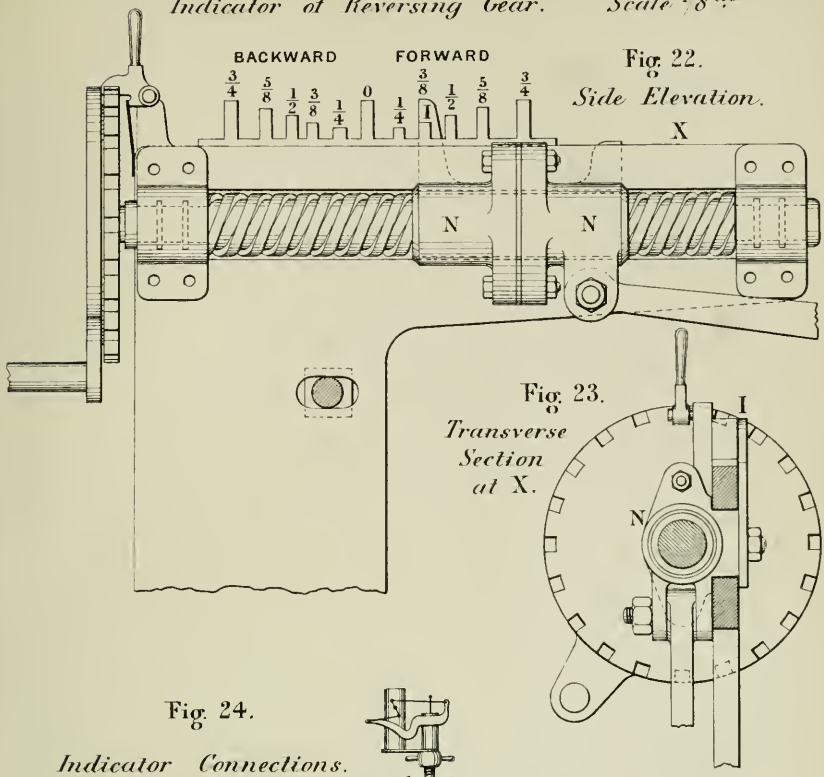
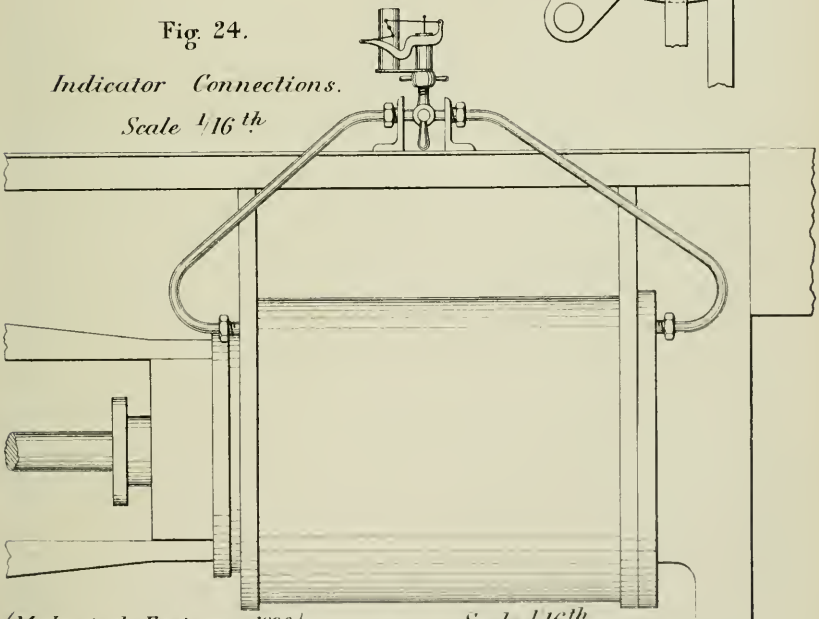


Fig. 22.
Side Elevation.

Fig. 23.
Transverse Section at X.

Fig. 24.
Indicator Connections.
Scale 1/16th



(Mechanical Engineers 1890) *Scale 1/16th*

Inches 12 6 0 1 2 3 Feet

Fig. 25. *Tractive Power of Passenger Engines.* *See Table 7.*

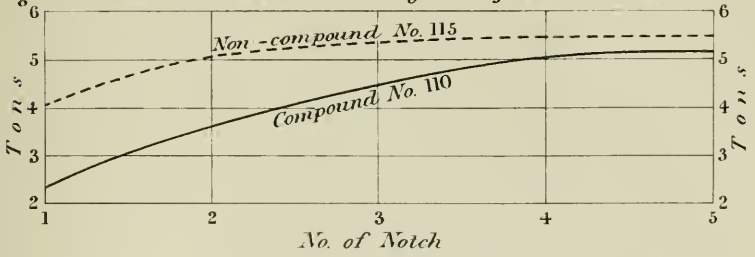


Fig. 26. *Tractive Power of Goods Engines.* *See Table 8.*

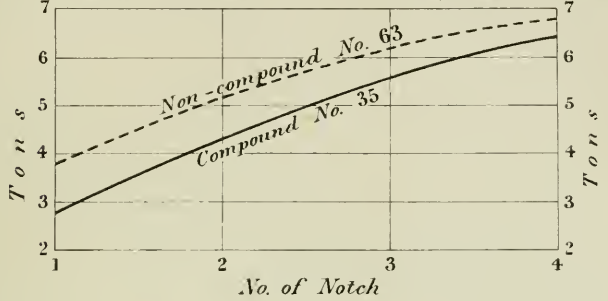
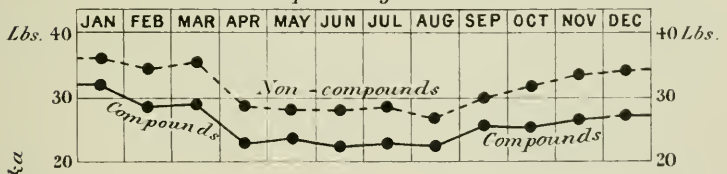
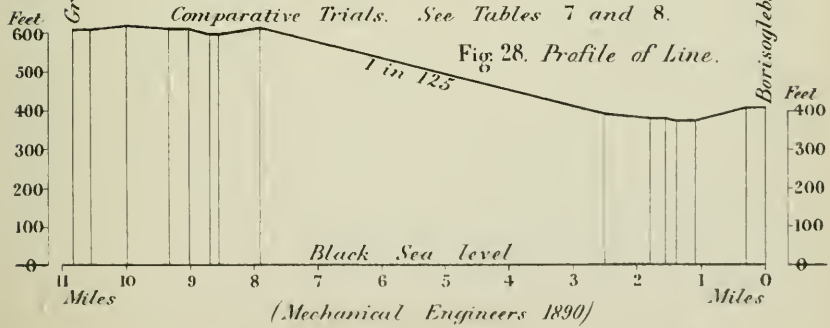


Fig. 27. *Consumption of Petroleum Refuse in 1889.* *See Table 10.*
Six-wheel coupled 36-ton Goods Engines.
Lbs. per Engine-mile.



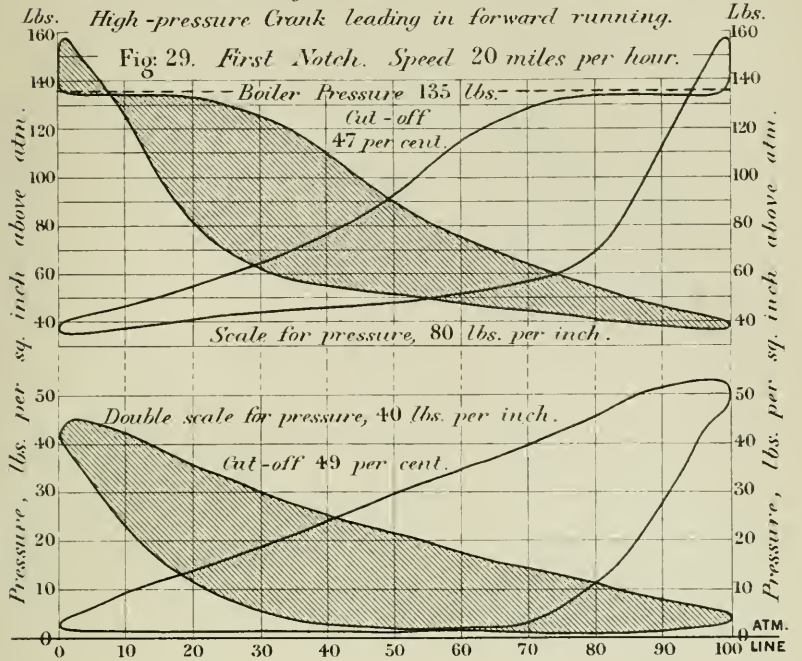
Compound and Non-compound Engines.
Comparative Trials. See Tables 7 and 8.

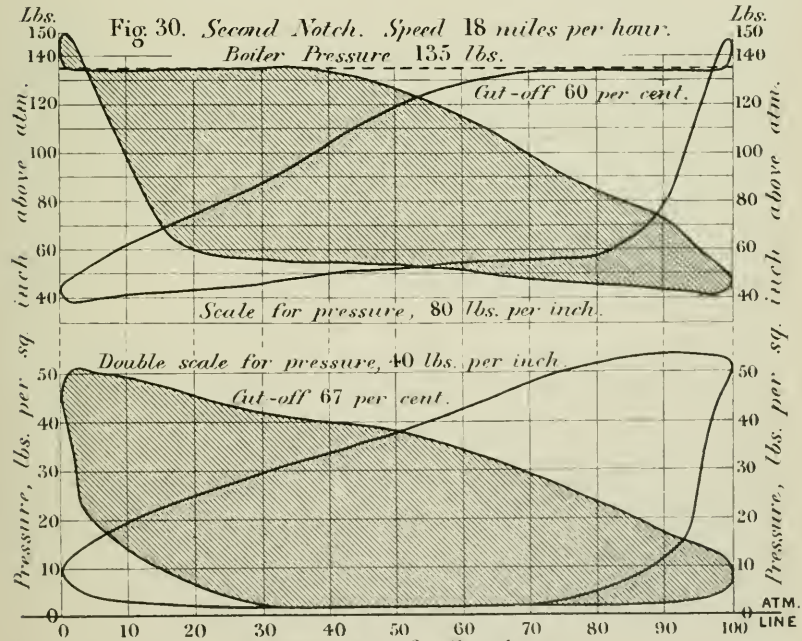
Fig. 28. *Profile of Line.*



(Mechanical Engineers 1890)

Compound Goods Engine N° 35. See Tables 1 and 2.


Lbs. High-pressure Crank leading in forward running. Lbs.
Fig. 29. First Notch. Speed 20 miles per hour.
Boiler Pressure 135 lbs.
Cut-off 47 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 49 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100


Lbs.
Fig. 30. Second Notch. Speed 18 miles per hour.
Boiler Pressure 135 lbs.
Cut-off 60 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 67 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100
Percentage of Stroke

(Mechanical Engineers 1890)

Compound Goods Engine № 35. See Tables 1 and 2.

High-pressure Crank leading in forward running.

Fig. 31. *Third Notch. Speed 17 miles per hour.*

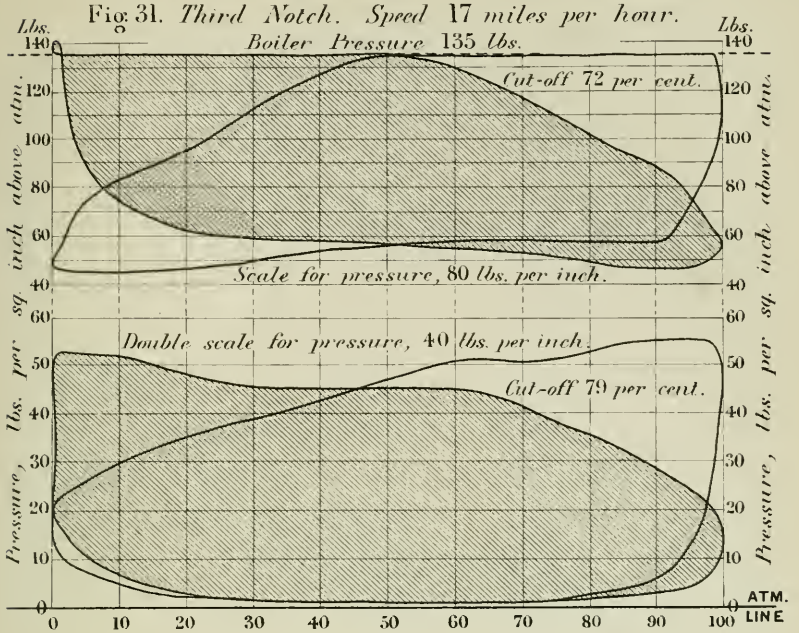
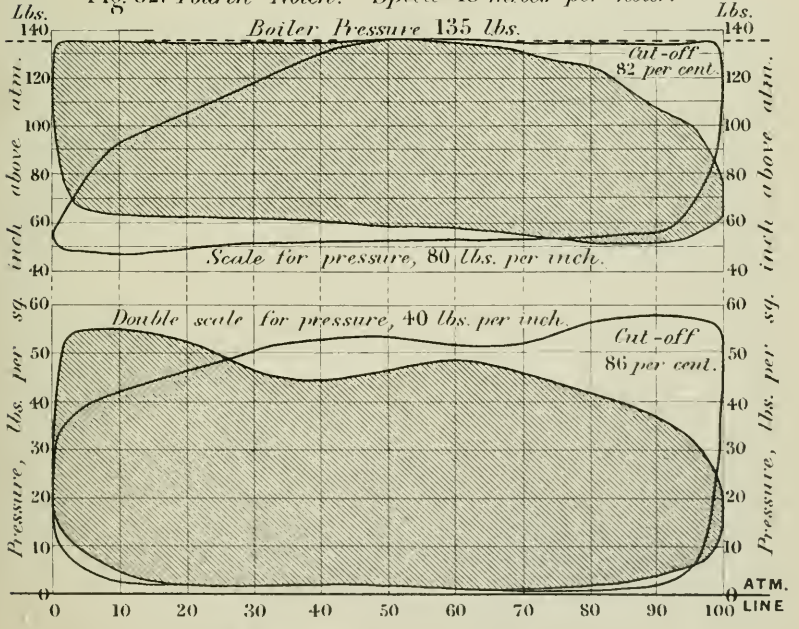

Lbs.
Boiler Pressure 135 lbs.
Cut-off 72 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 79 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100

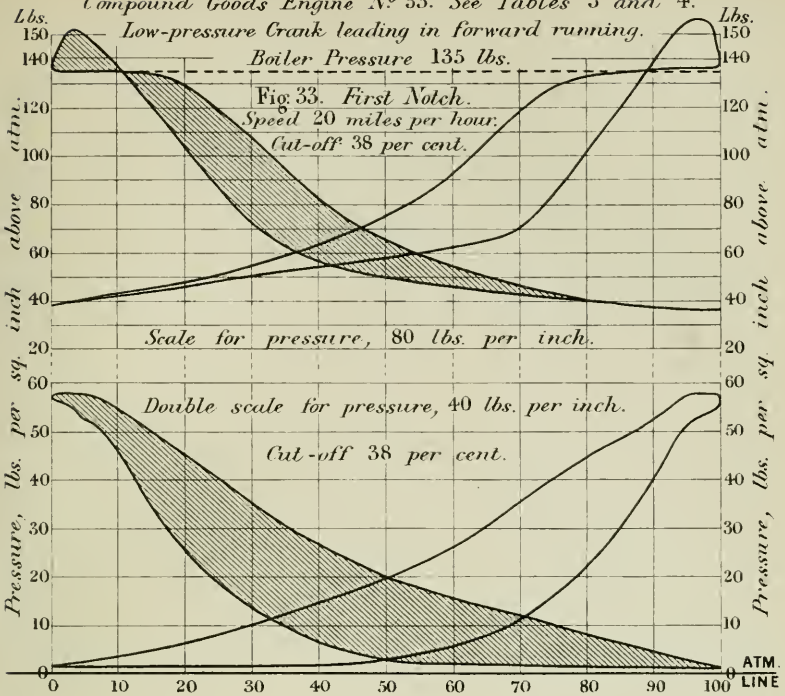
Fig. 32. *Fourth Notch. Speed 13 miles per hour.*

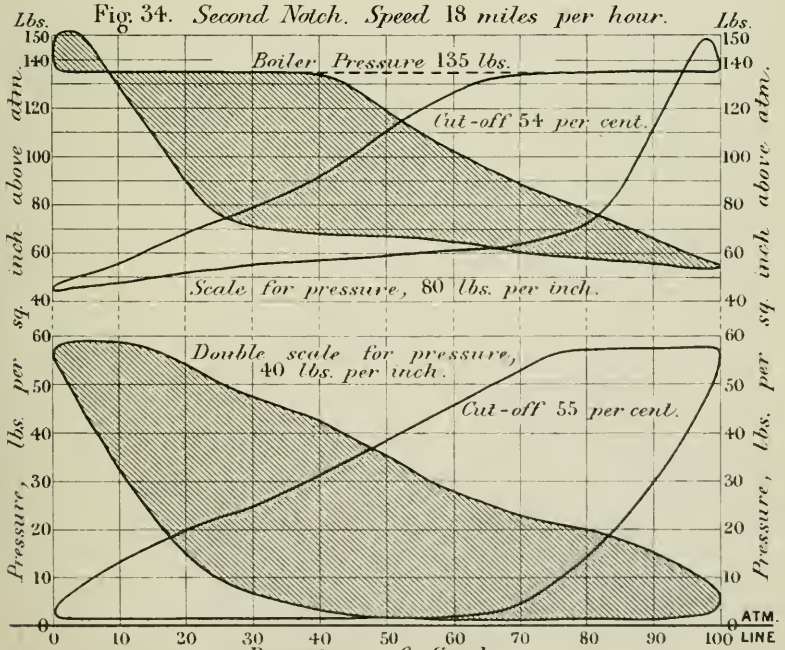

Lbs.
Boiler Pressure 135 lbs.
Cut-off 82 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 86 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100
Percentage of Stroke

(Mechanical Engineers 1890)

COMPOUNDING OF LOCOMOTIVES. *Plate 13.*

Compound Goods Engine N° 53. See Tables 3 and 4.


Lbs.
Low-pressure Crank leading in forward running.
Boiler Pressure 135 lbs.
Fig. 33. First Notch.
Speed 20 miles per hour.
Cut-off 38 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 38 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE


Lbs.
Fig. 34. Second Notch. Speed 18 miles per hour.
Boiler Pressure 135 lbs.
Cut-off 54 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 55 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
Percentage of Stroke

(Mechanical Engineers 1890)

Compound Goods Engine N° 53. See Tables 3 and 4.
Low-pressure Crank leading in forward running.

Fig. 35. *Third Notch. Speed 15 miles per hour.*

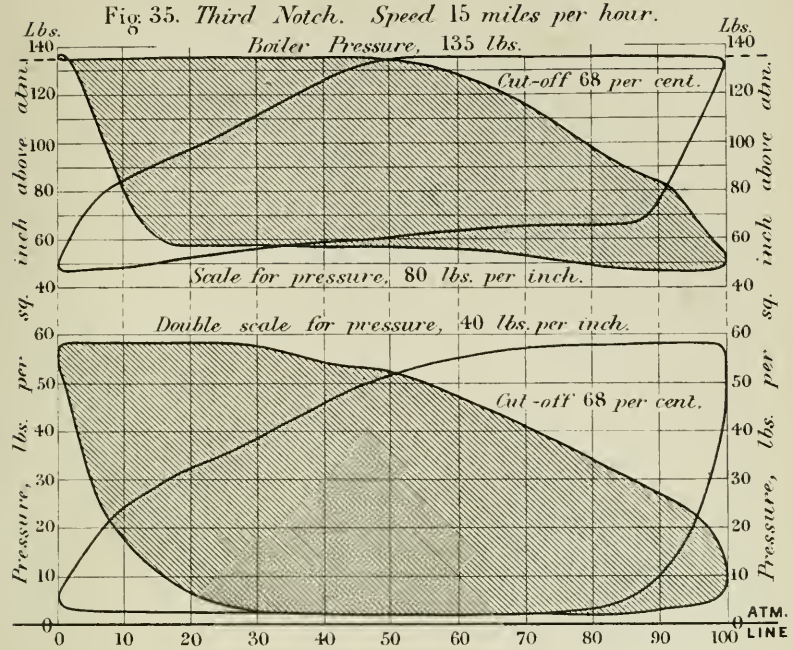
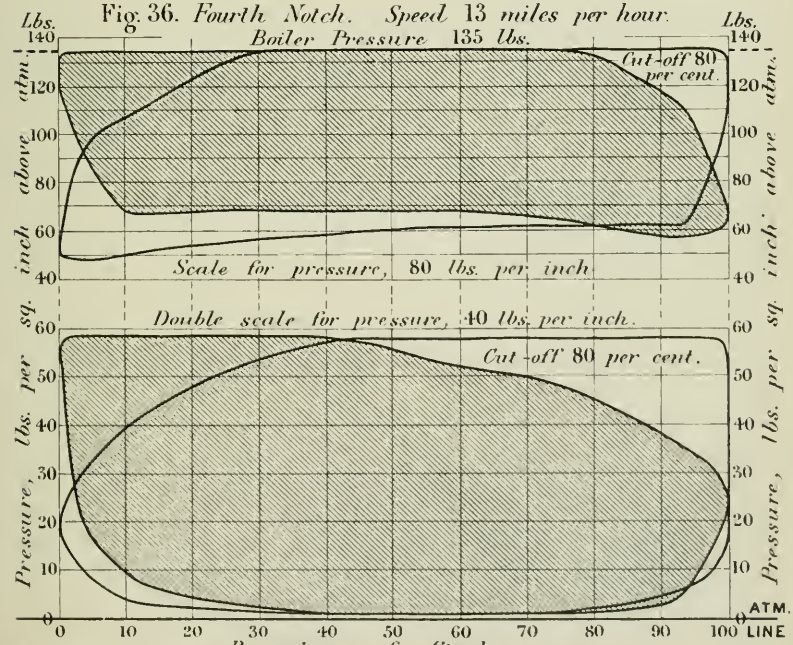

Lbs.
Boiler Pressure, 135 lbs.
Cut-off 68 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 68 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE

Fig. 36. *Fourth Notch. Speed 13 miles per hour.*


Lbs.
Boiler Pressure 135 lbs.
Cut-off 80 per cent.
Scale for pressure, 80 lbs. per inch
Double scale for pressure, 40 lbs. per inch.
Cut-off 80 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
Percentage of Stroke.

(Mechanical Engineers 1890)

Compound Passenger Engine № 110. See Tables 5 and 6.
High-pressure Crank leading in forward running.

Fig. 37. *First Notch. Speed 33 miles per hour.*

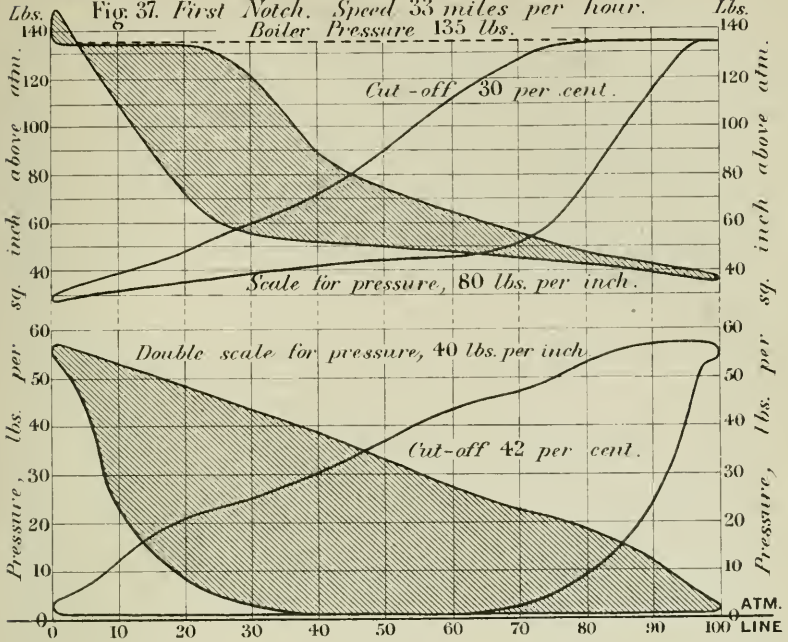
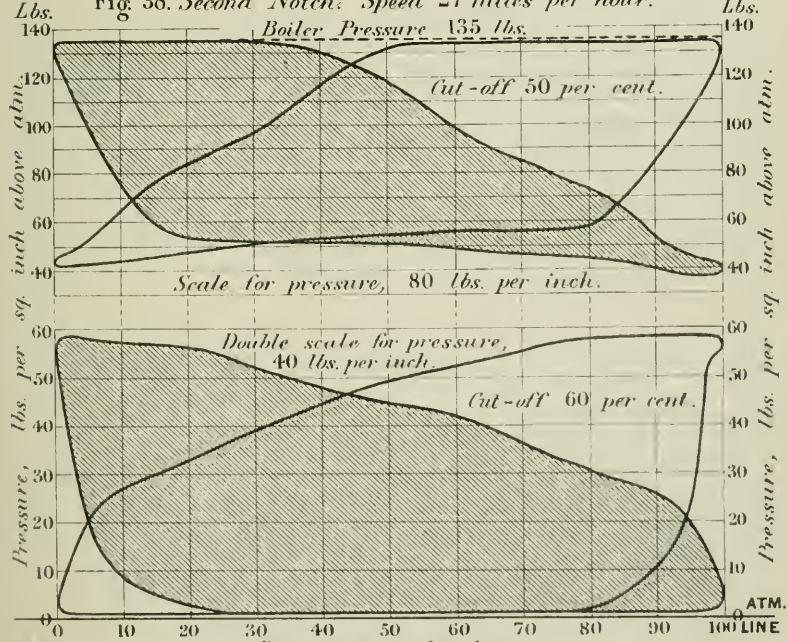

Lbs.
Boiler Pressure 135 lbs.
Cut-off 30 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 42 per cent.
lbs. per sq. inch above atm.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100

Fig. 38. *Second Notch. Speed 27 miles per hour.*


Lbs.
Boiler Pressure 135 lbs.
Cut-off 50 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 60 per cent.
lbs. per sq. inch above atm.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100
Percentage of Stroke

(Mechanical Engineers 1890)

Compound Passenger Engine No 110. See Tables 5 and 6.
High-pressure Crank leading in forward running.

Fig. 39. *Third Notch, Speed 20 miles per hour.*

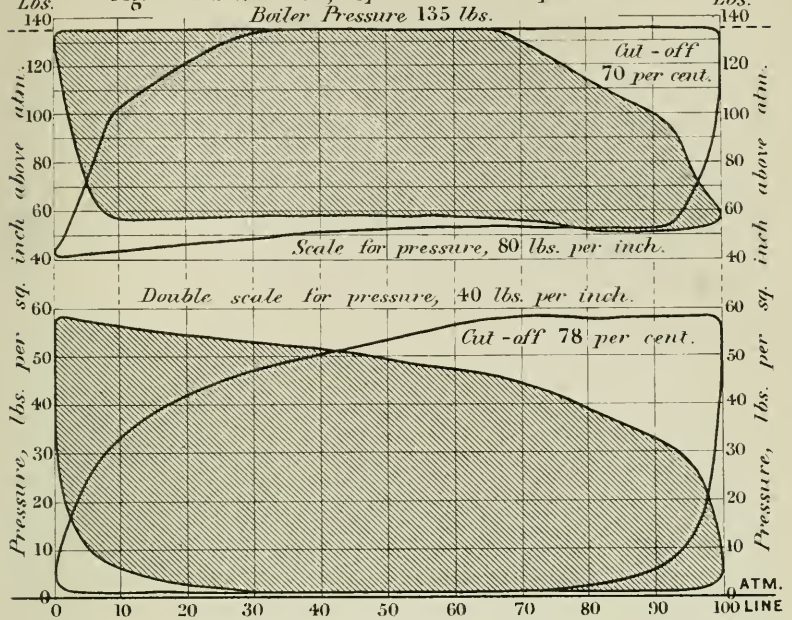
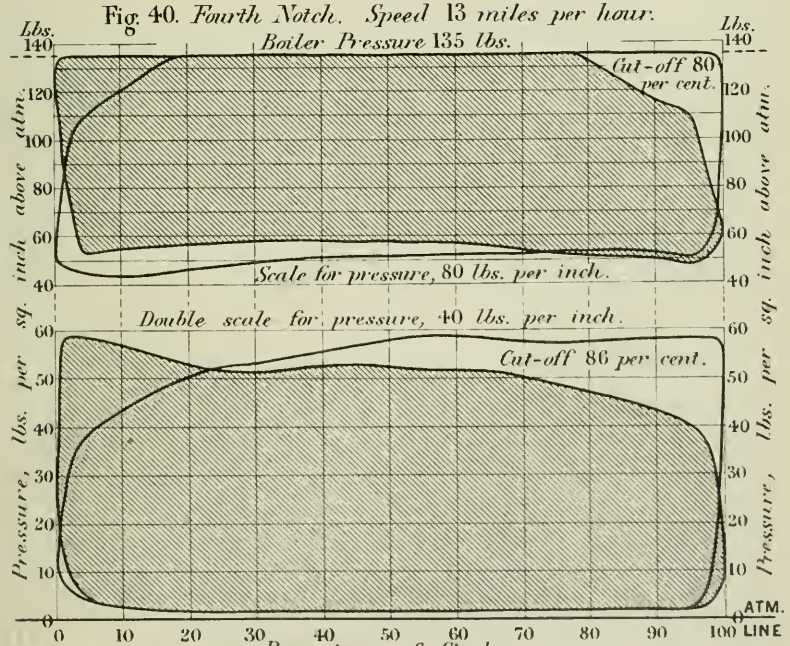

Lbs.
Boiler Pressure 135 lbs.
Cut-off 70 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 78 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE

Fig. 40. *Fourth Notch. Speed 13 miles per hour.*


Lbs.
Boiler Pressure 135 lbs.
Cut-off 80 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 86 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
Percentage of Stroke

(Mechanical Engineers 1890)

COMPOUNDING OF LOCOMOTIVES. *Plate 17.*

Compound Passenger Engine No 110. See Table 7.
Constant Speed of 10 miles per hour.

Fig. 41. *First Notch. Cut-off 30 per cent.*

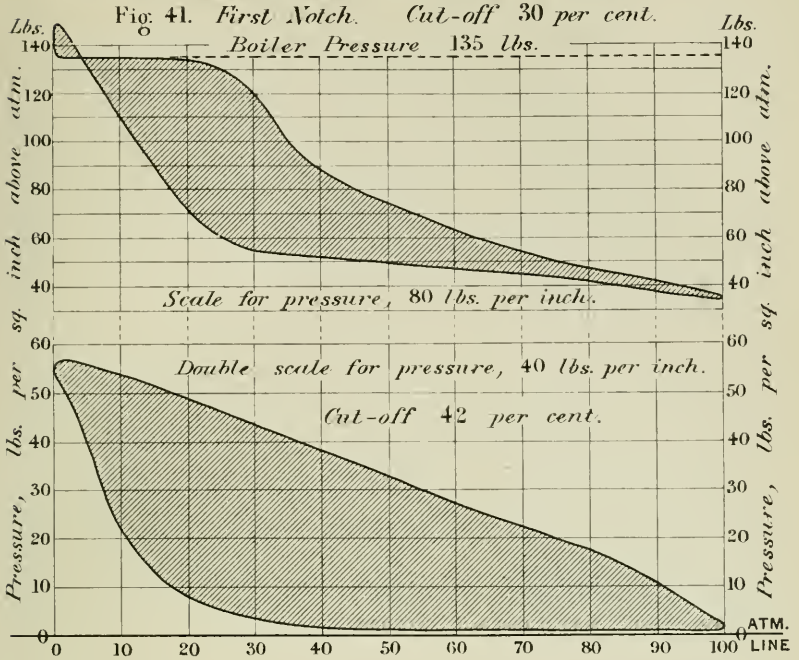
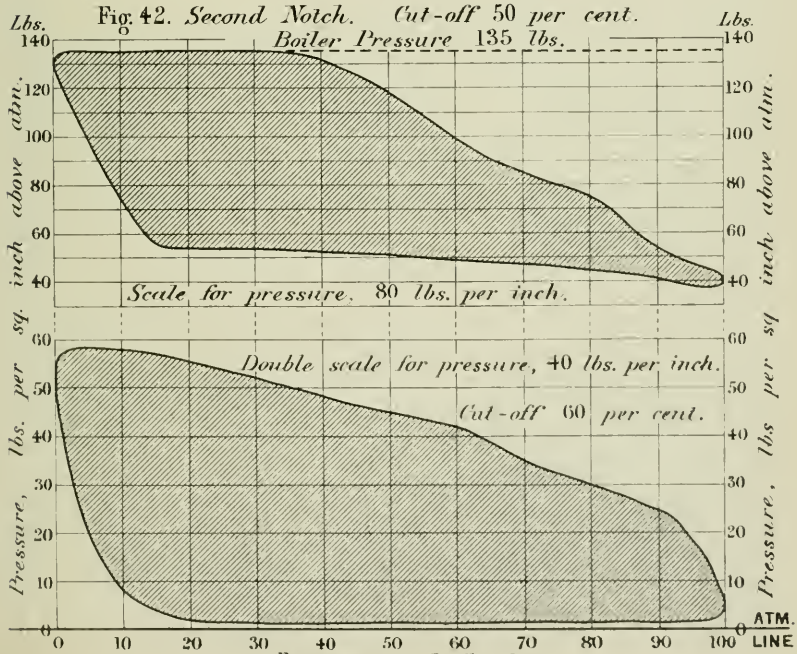

Lbs.
Boiler Pressure 135 lbs.
Lbs.
Pressure, lbs. per sq. inch above atm.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 42 per cent.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100

Fig. 42. *Second Notch. Cut-off 50 per cent.*


Lbs.
Boiler Pressure 135 lbs.
Lbs.
Pressure, lbs. per sq. inch above atm.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 60 per cent.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100
Percentage of Stroke

(Mechanical Engineers 1890)

COMPOUNDING OF LOCOMOTIVES. *Plate 18.*

Compound Passenger Engine No 110. See Table 7.

Constant Speed of 10 miles per hour.

Fig. 43. *Third Notch. Cut-off 70 per cent.*

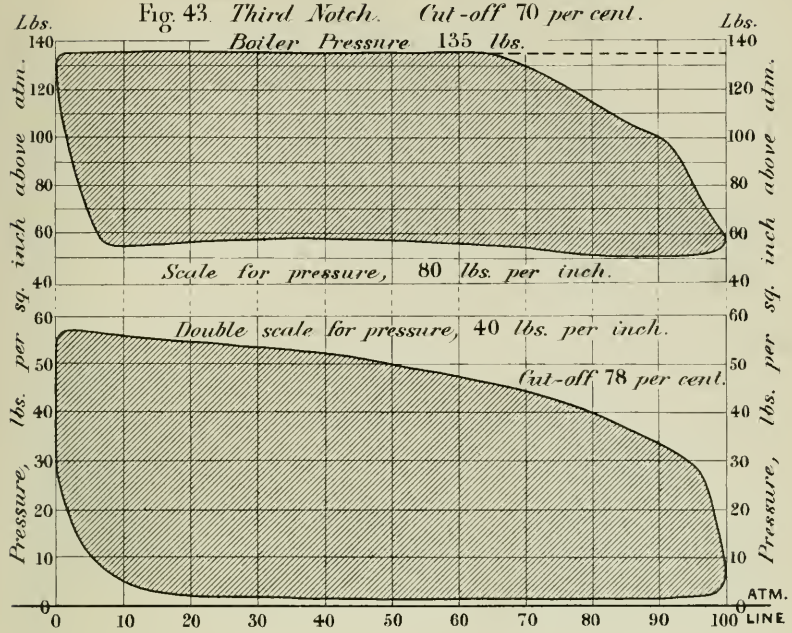
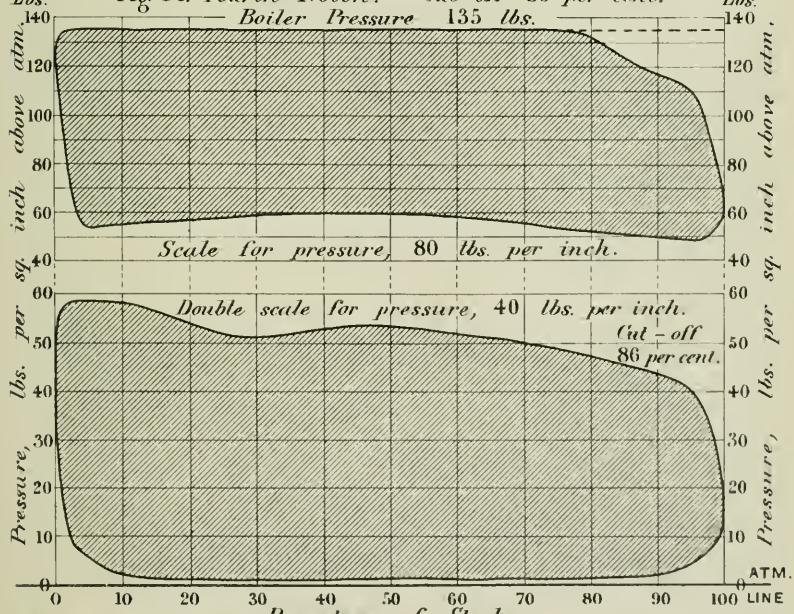

Lbs.
Lbs.
Boiler Pressure 135 lbs.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 78 per cent.
Pressure, lbs. per sq. inch above atm.
ATM.
LINE
0 10 20 30 40 50 60 70 80 90 100

Fig. 44. *Fourth Notch. Cut-off 80 per cent.*


Lbs.
Lbs.
Boiler Pressure 135 lbs.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 86 per cent.
Pressure, lbs. per sq. inch above atm.
ATM.
LINE
0 10 20 30 40 50 60 70 80 90 100
Percentage of Stroke

(Mechanical Engineers 1890)

Non-compound Passenger Engine No 115. *See Table* 7.
Constant Speed of 10 *miles per hour. Boiler Pressure* 135 *lbs.*

Fig. 45. *First Notch. Cut-off* 33 *per cent.*

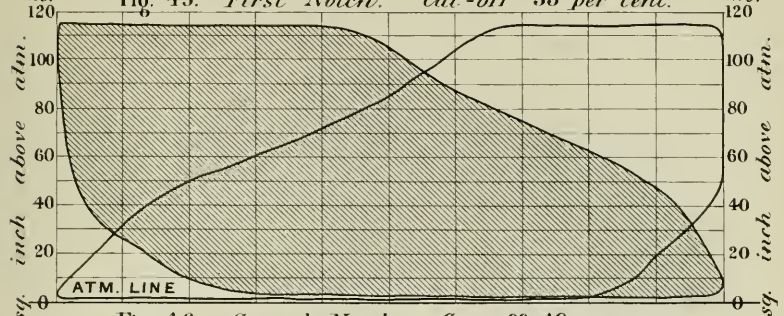


Fig. 46. *Second Notch. Cut-off* 49 *per cent.*

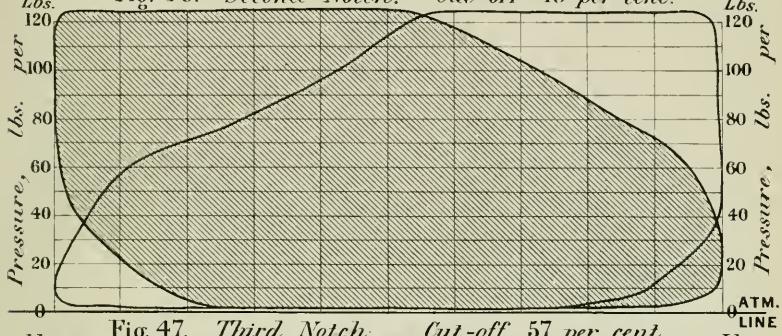


Fig. 47. *Third Notch. Cut-off* 57 *per cent.*

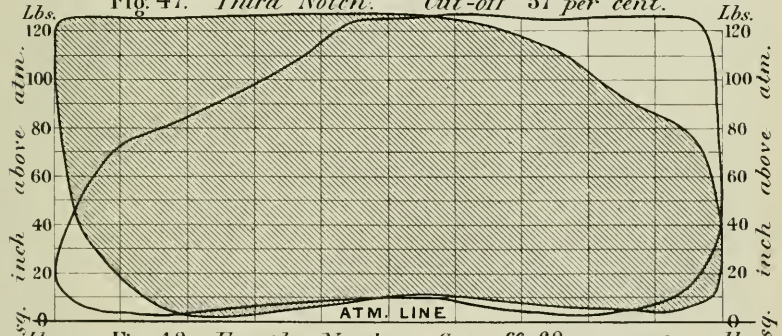
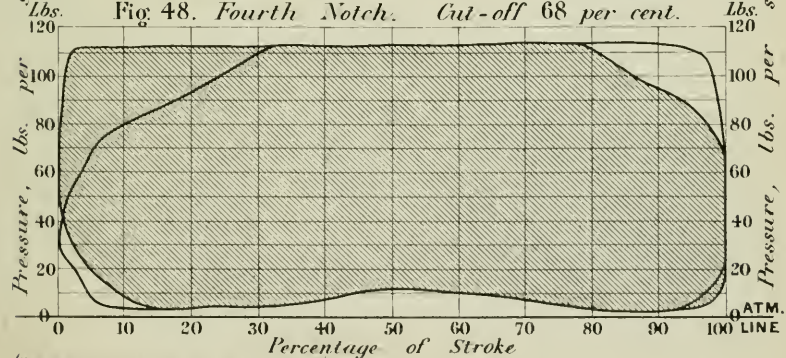


Fig. 48. *Fourth Notch. Cut-off* 68 *per cent.*

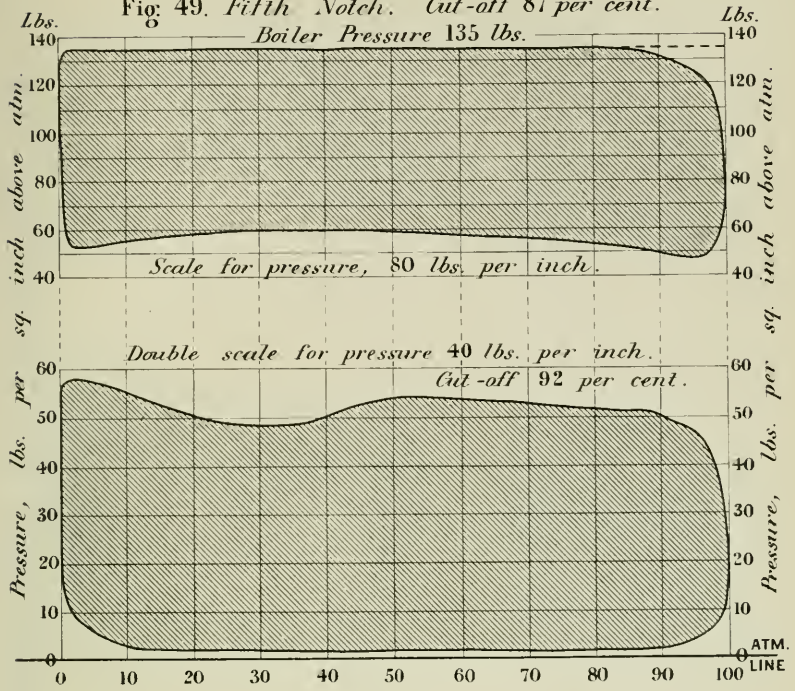


(Mechanical Engineers 1890)

Compound Passenger Engine № 110. *See Table* 7.

Constant Speed of 10 *miles per hour.*

Fig. 49. *Fifth Notch. Cut-off* 87 *per cent.*

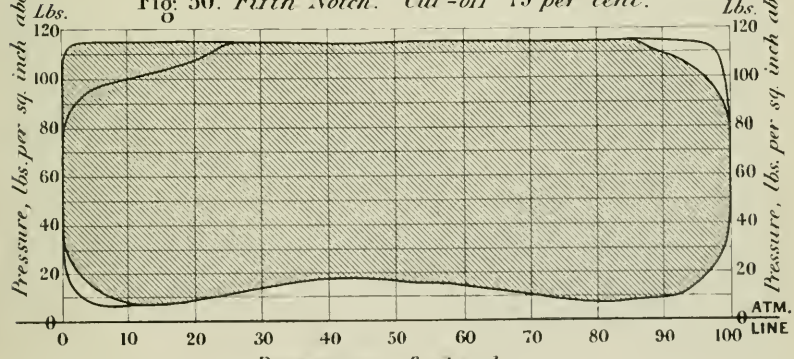

Lbs.
Boiler Pressure 135 lbs.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure 40 lbs. per inch.
Cut-off 92 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100

Non-compound Passenger Engine № 115. *See Table* 7.

Constant Speed of 10 *miles per hour.*

Boiler Pressure 135 *lbs.*

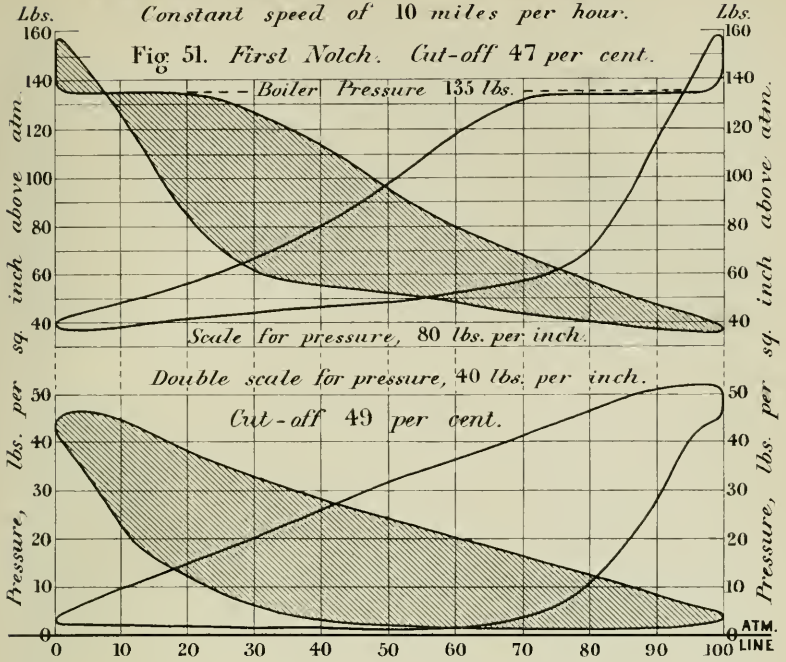
Fig. 50. *Fifth Notch. Cut-off* 79 *per cent.*

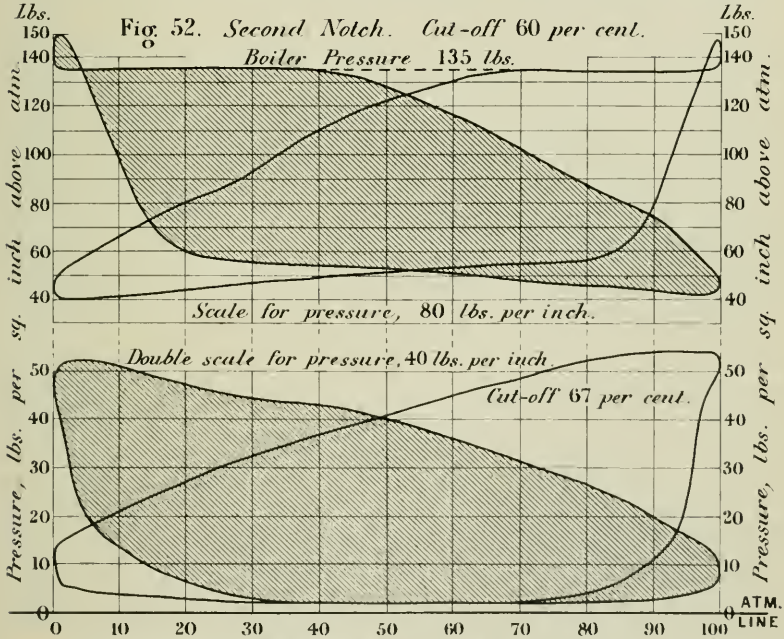


(Mechanical Engineers 1890)

Compound Goods Engine № 35. See Table 8.

Constant speed of 10 miles per hour.


Lbs.
Lbs.
Fig. 51. First Notch. Cut-off 47 per cent.
Boiler Pressure 135 lbs.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 49 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100


Lbs.
Lbs.
Fig. 52. Second Notch. Cut-off 60 per cent.
Boiler Pressure 135 lbs.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 67 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100
Percentage of Stroke

(Mechanical Engineers 1890)

COMPOUNDING OF LOCOMOTIVES. *Plate 22.*

Compound Goods Engine N° 35. See Table 8.

Constant Speed of 10 miles per hour.

Fig. 53. *Third Notch. Cut-off 72 per cent.*

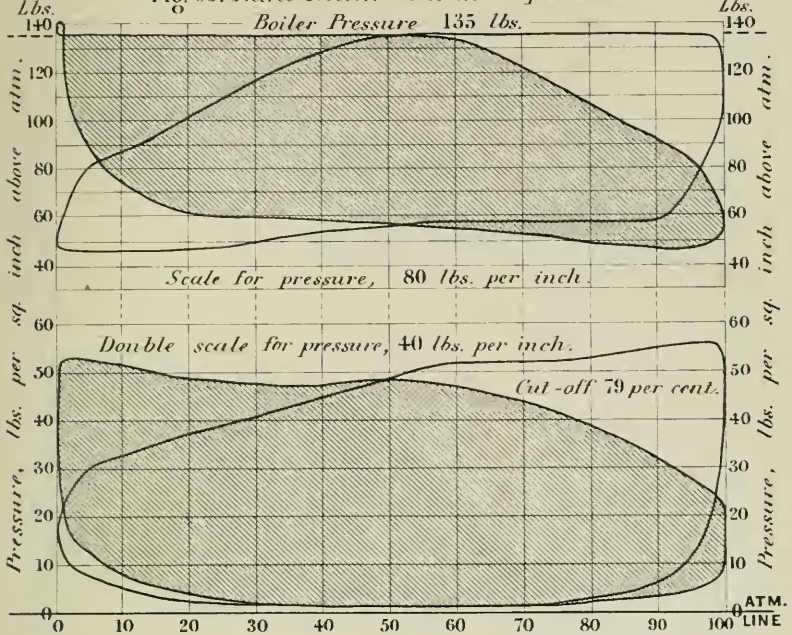
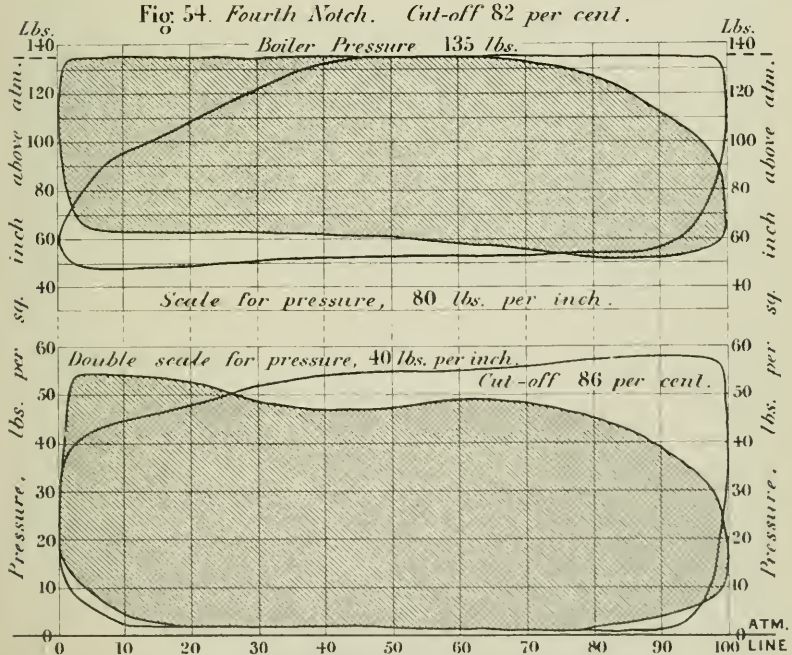

Lbs.
Boiler Pressure 135 lbs.
Lbs. per sq. inch above atm.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 79 per cent.
Pressure, lbs. per sq. inch
ATM. LINE

Fig. 54. *Fourth Notch. Cut-off 82 per cent.*


Lbs.
Boiler Pressure 135 lbs.
Lbs. per sq. inch above atm.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 86 per cent.
Pressure, lbs. per sq. inch
ATM. LINE
Percentage of Stroke

(Mechanical Engineers 1890)

Non-compound Goods Engine № 63. *See Table* 8.

Constant Speed of 10 *miles per hour. Boiler Pressure* 135 *lbs.*

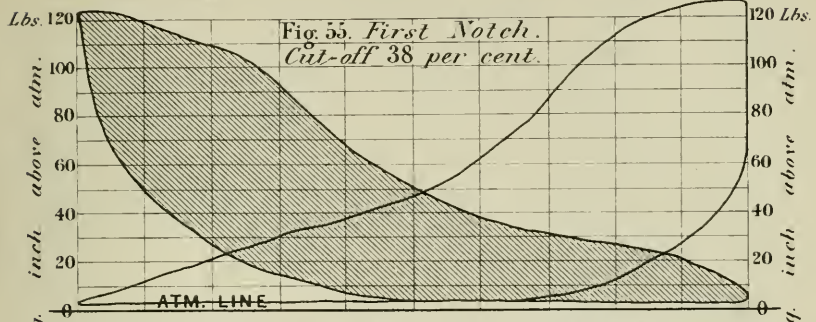


Fig. 55. *First Notch. Cut-off* 38 *per cent.*

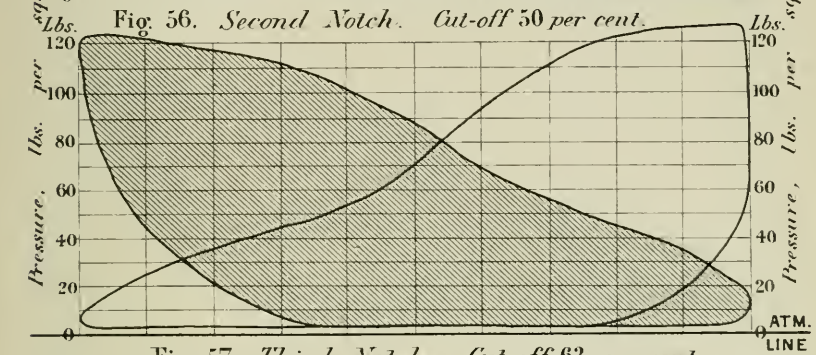


Fig. 56. *Second Notch. Cut-off* 50 *per cent.*

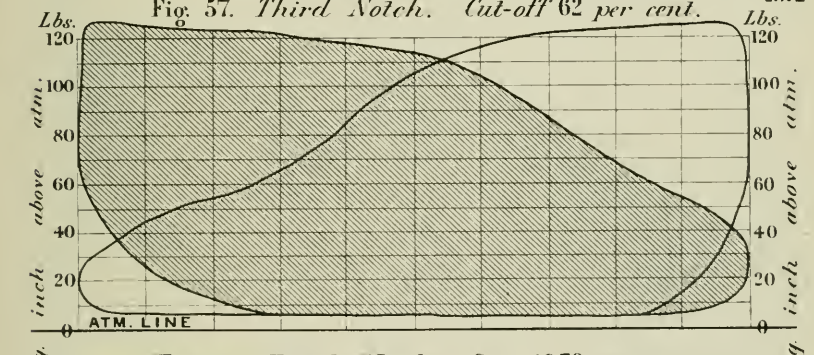


Fig. 57. *Third Notch. Cut-off* 62 *per cent.*

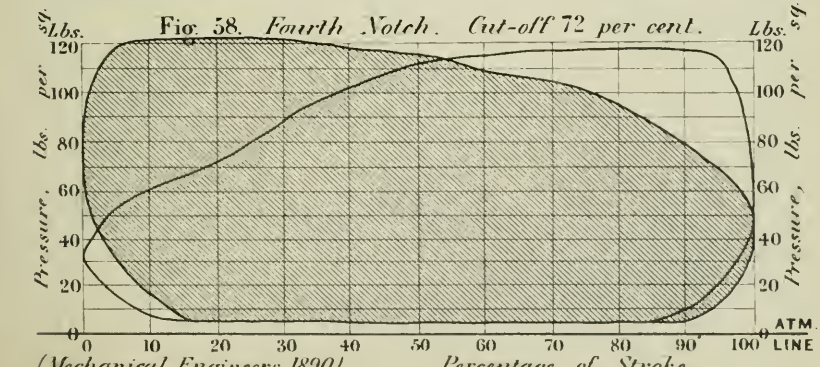
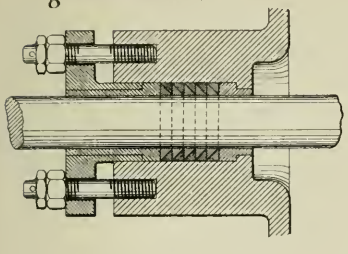


Fig. 58. *Fourth Notch. Cut-off* 72 *per cent.*

(Mechanical Engineers 1890)

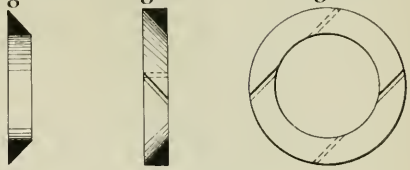
Metallic Packing for Stuffing-boxes.

Fig. 59. *Scale 1/10th*

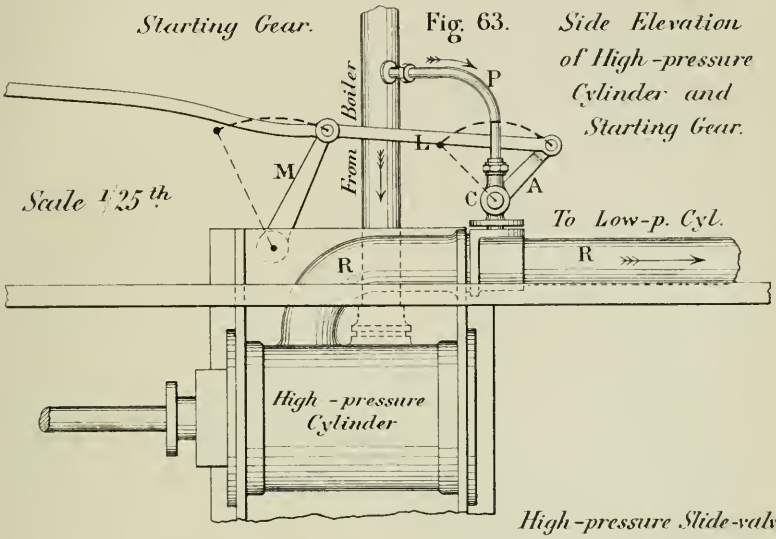


Packing Rings. *Scale 1/5th*

Fig. 60. Fig. 61. Fig. 62.



Starting Gear. Fig. 63. *Side Elevation of High-pressure Cylinder and Starting Gear.*



Scale 1/25th

High-pressure Slide-valve.

Fig. 64. *Starting Cock.*

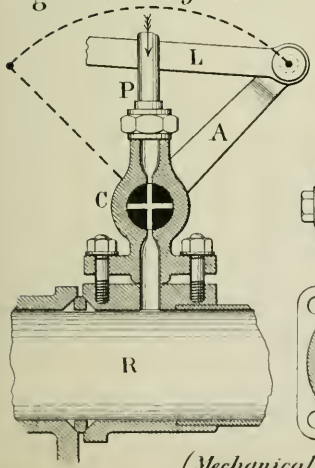
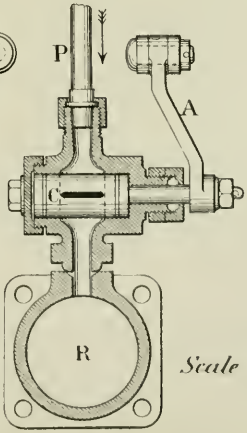


Fig. 65.



Scale 1/10th

Fig. 66. *Longitudinal Section*

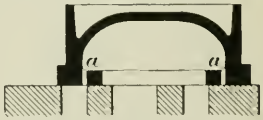
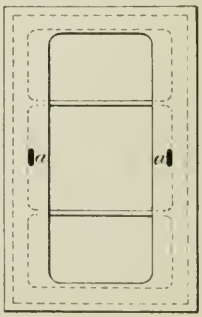


Fig. 67. *Plan inverted.*



(Mechanical Engineer 1890)

Eight-wheel coupled Goods Engine No 68.

Fig. 68. *Elevation of Low-pressure side.*

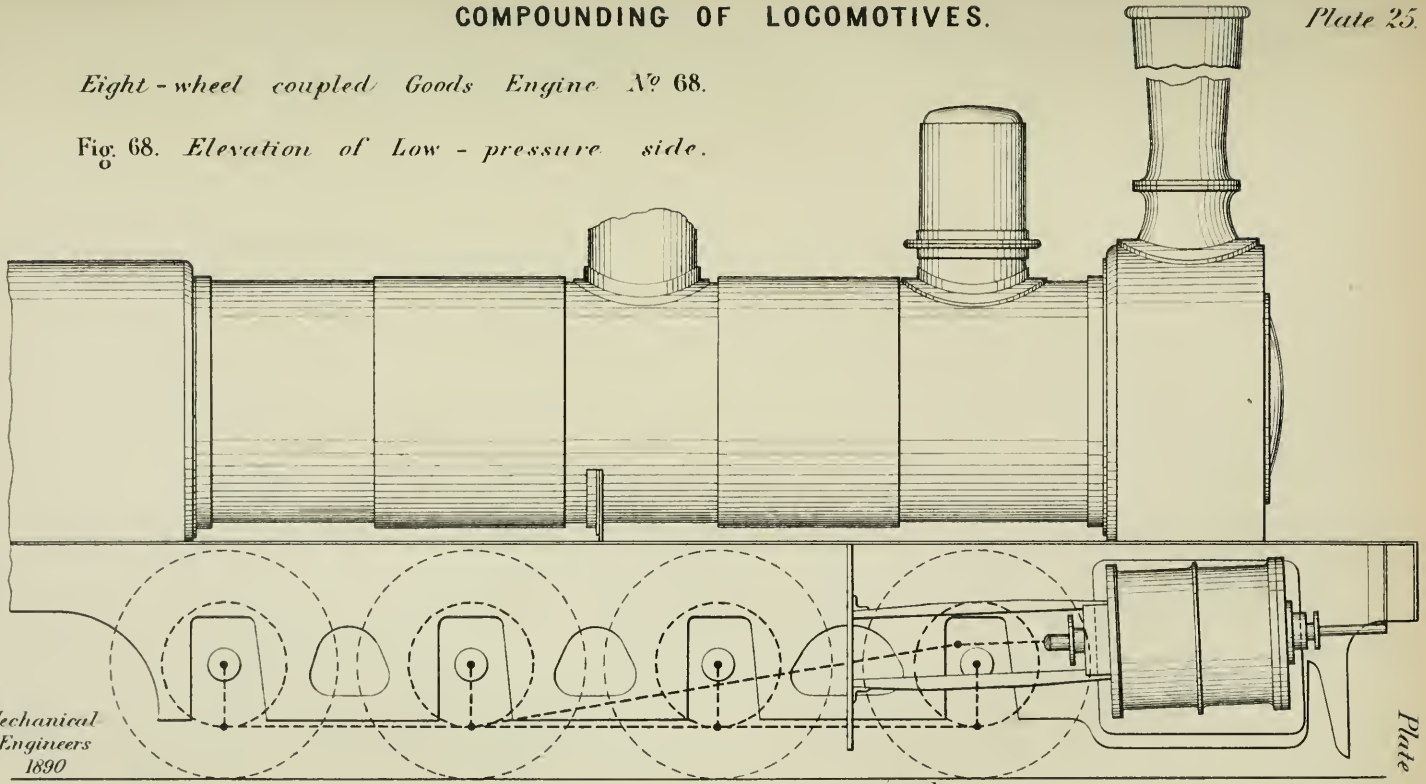


Plate 25.

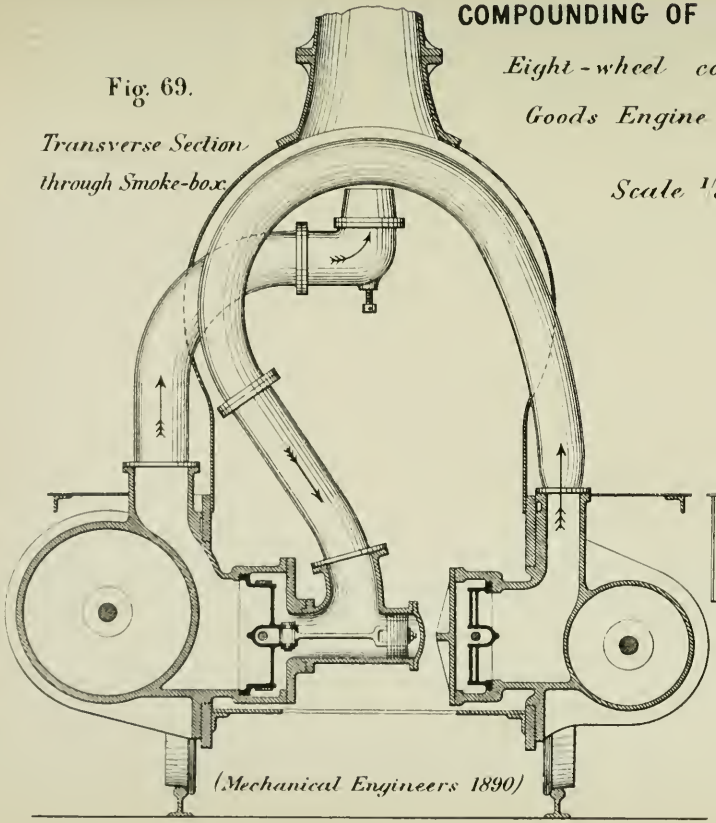
COMPOUNDING OF LOCOMOTIVES.

Eight-wheel coupled Goods Engine No 68.

Scale 1/30th

Fig. 69.

Transverse Section through Smoke-box.



(Mechanical Engineers 1890)

Fig. 70.

Elevation of High-Pressure side.

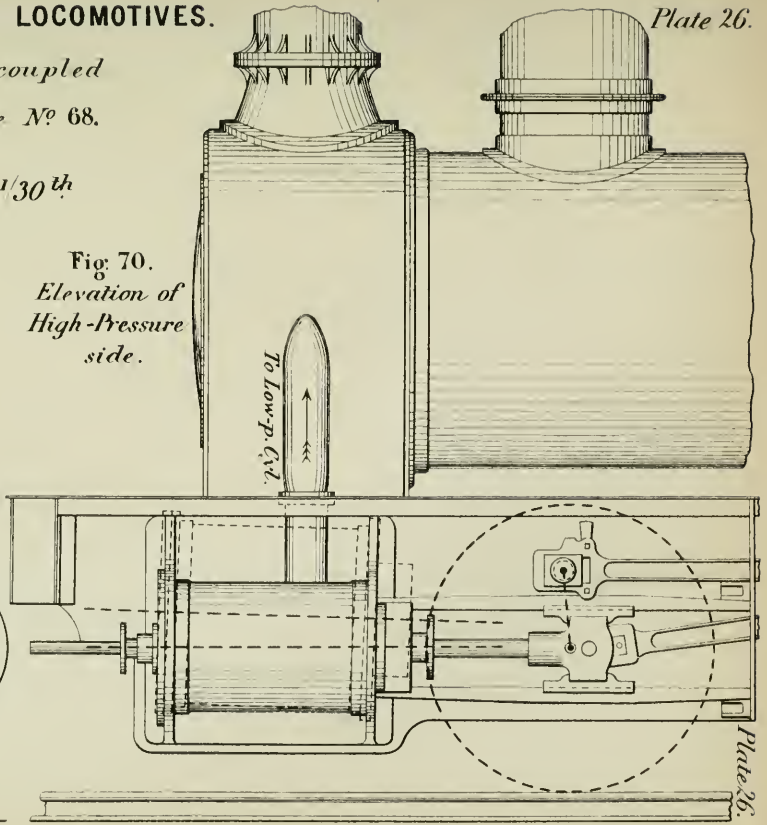
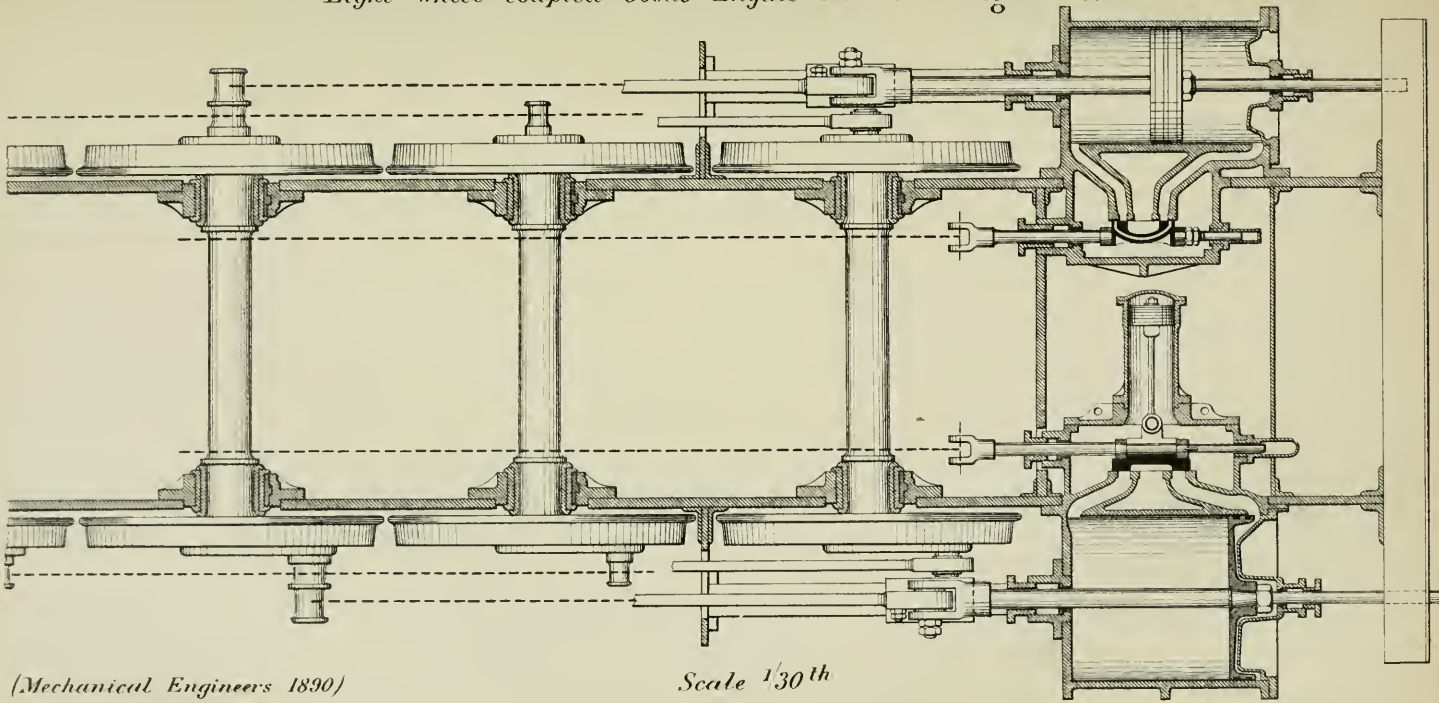


Plate 26.

Eight-wheel coupled Goods Engine № 68. Fig. 71. *Plan.*



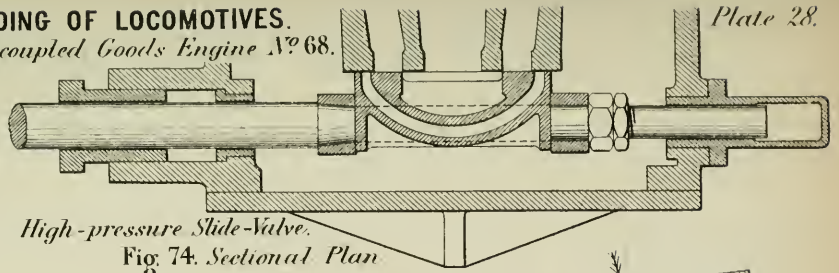
(Mechanical Engineers 1890) *Scale 1/30th*

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet

Plate 27.

COMPOUNDING OF LOCOMOTIVES.

Eight-wheel coupled Goods Engine N° 68.



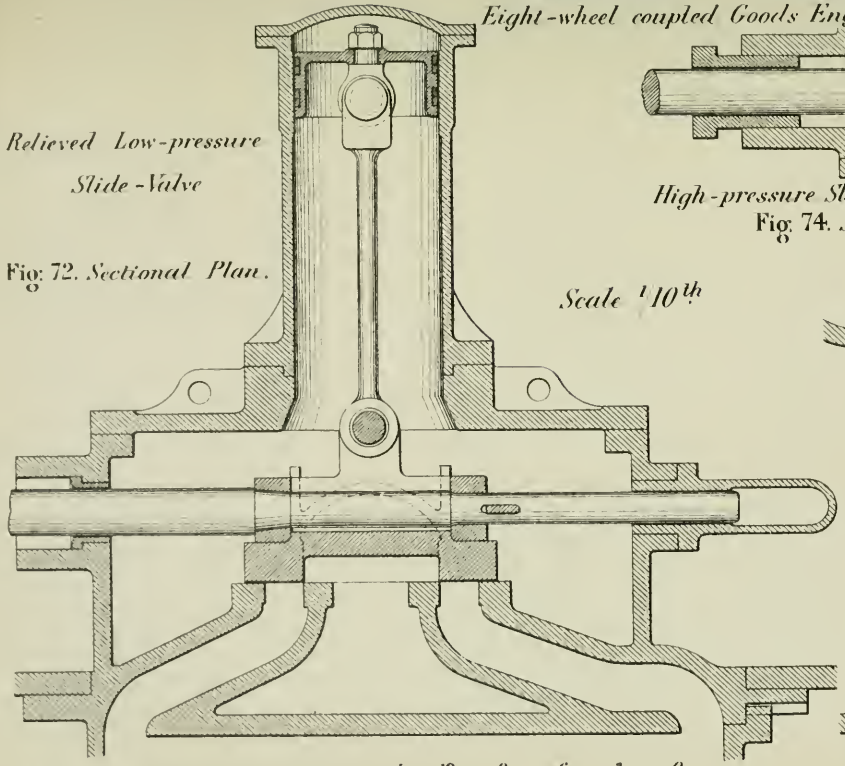
High-pressure Slide-Valve.

Fig. 74. *Sectional Plan*

Relieved Low-pressure Slide-Valve

Fig. 72. *Sectional Plan.*

Scale 1/10th



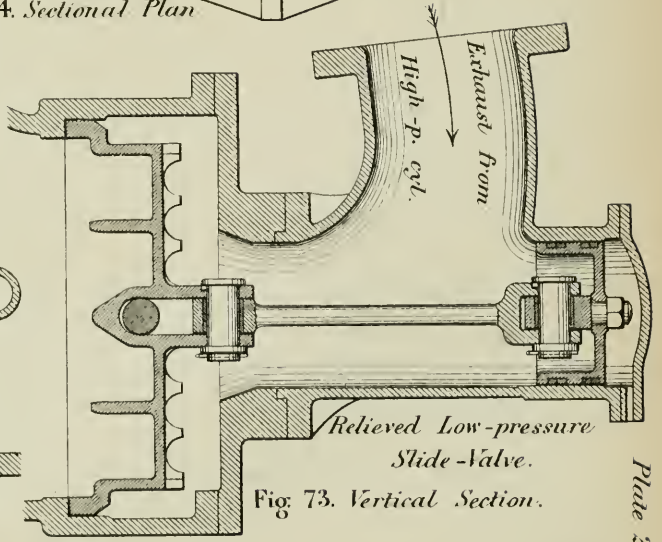
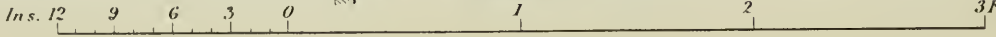
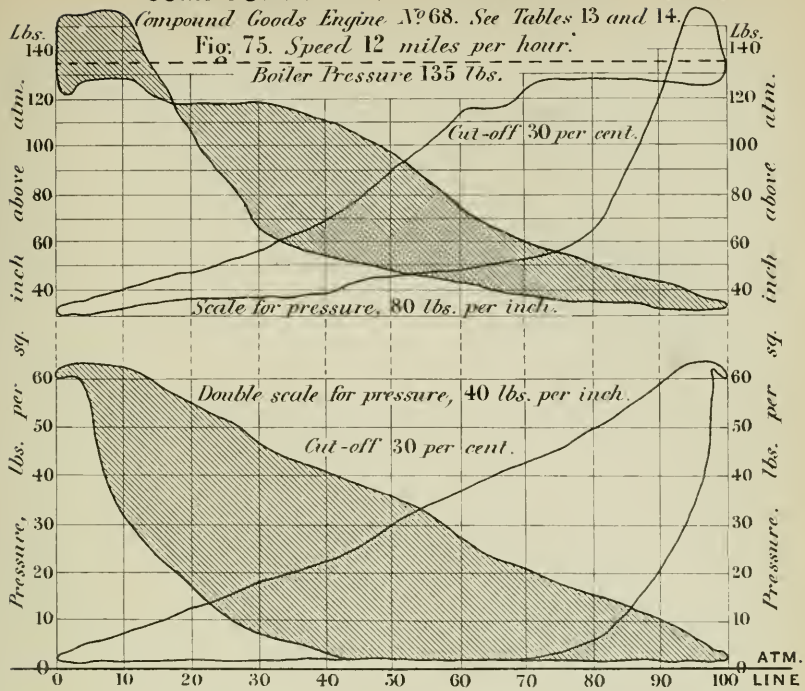


Fig. 73. *Vertical Section.*



(Mechanical Engineers 1890)

Plate 28.


Compound Goods Engine № 68. See Tables 13 and 14.
Fig: 75. Speed 12 miles per hour.
Boiler Pressure 135 lbs.
Cut-off 30 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 30 per cent.
Lbs. per sq. inch above atm.
Pressure.
Lbs.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100

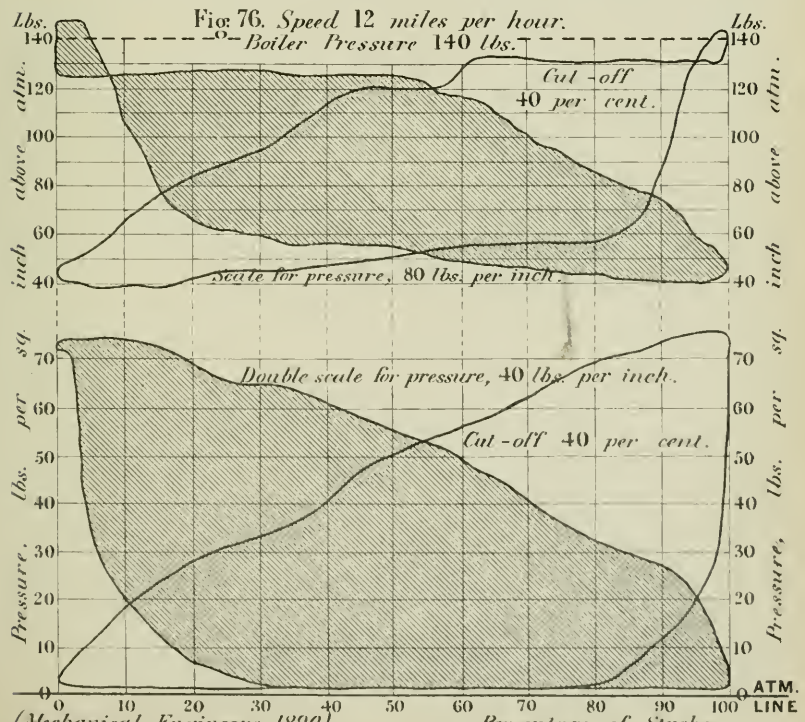


Fig: 76. Speed 12 miles per hour.
Boiler Pressure 140 lbs.
Cut-off 40 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 40 per cent.
Lbs. per sq. inch above atm.
Pressure.
Lbs.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100
Percentage of Stroke

(Mechanical Engineers 1890)

COMPOUNDING OF LOCOMOTIVES. *Plate 30.*

Compound Goods Engine № 68. See Tables 13 and 14.

Fig. 77. *Speed 12 miles per hour.*

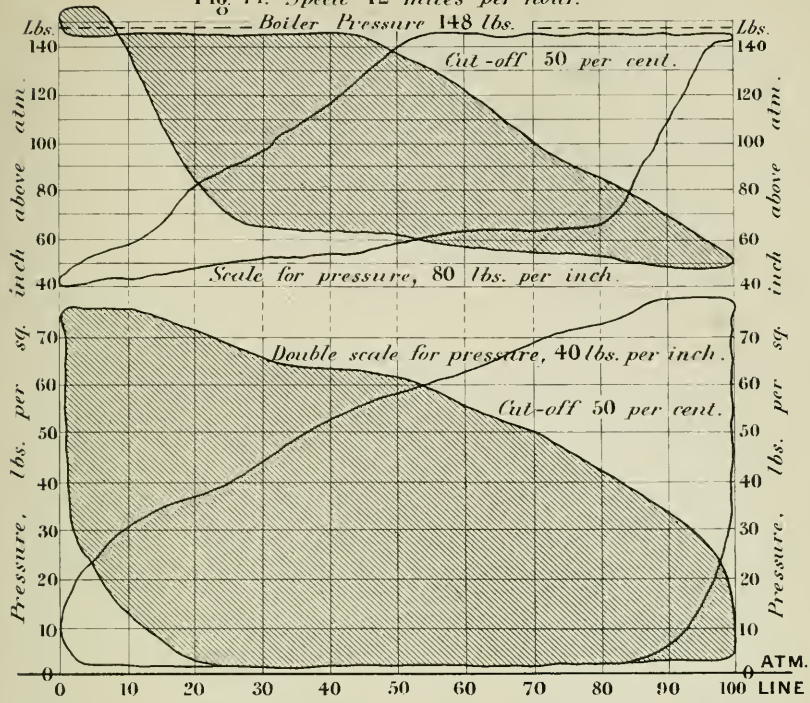
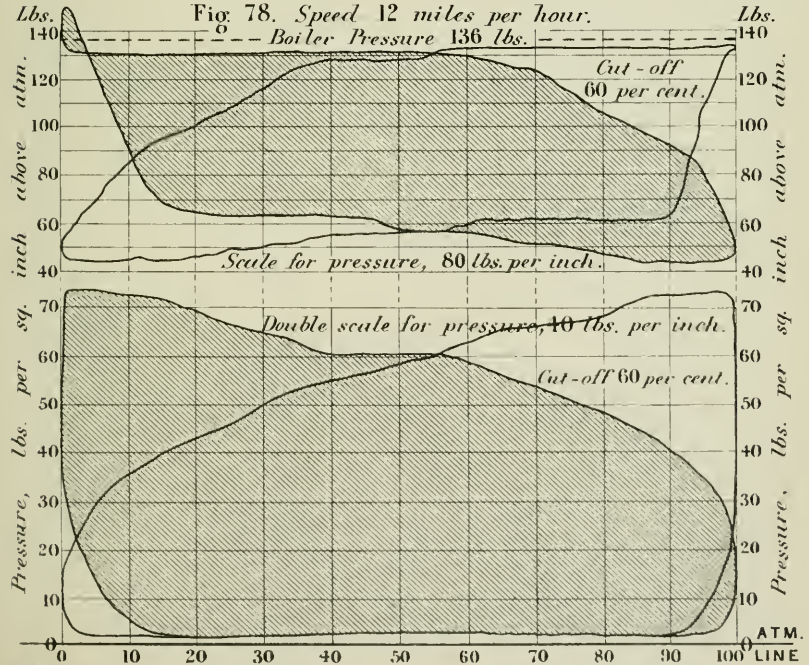

Lbs.
Boiler Pressure 148 lbs.
Cut-off 50 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 50 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100

Fig. 78. *Speed 12 miles per hour.*


Lbs.
Boiler Pressure 136 lbs.
Cut-off 60 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 60 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100

(Mechanical Engineers 1890) *Percentage of Stroke*

Compound Goods Engine № 68. See Tables 13 and 14.

Fig: 79. *Speed 12 miles per hour.*

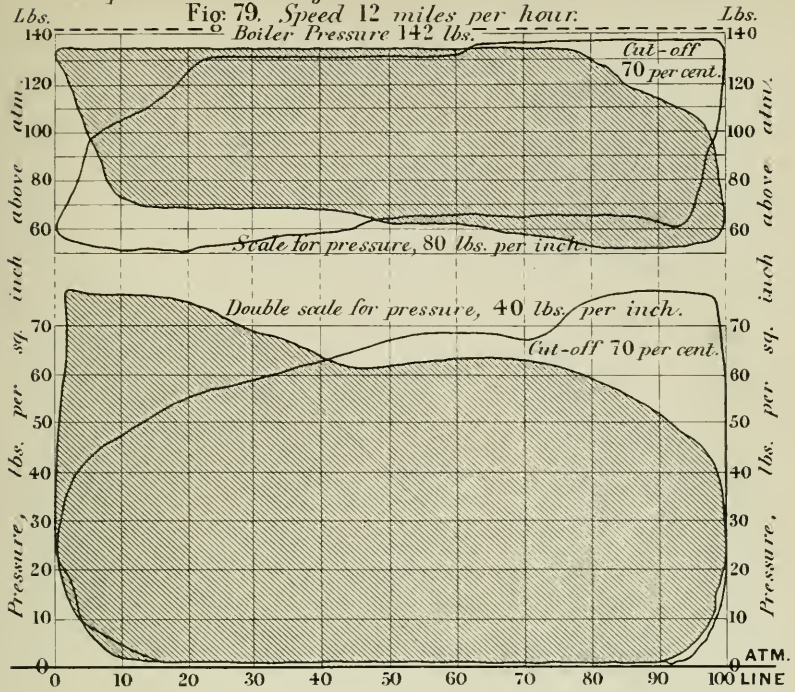
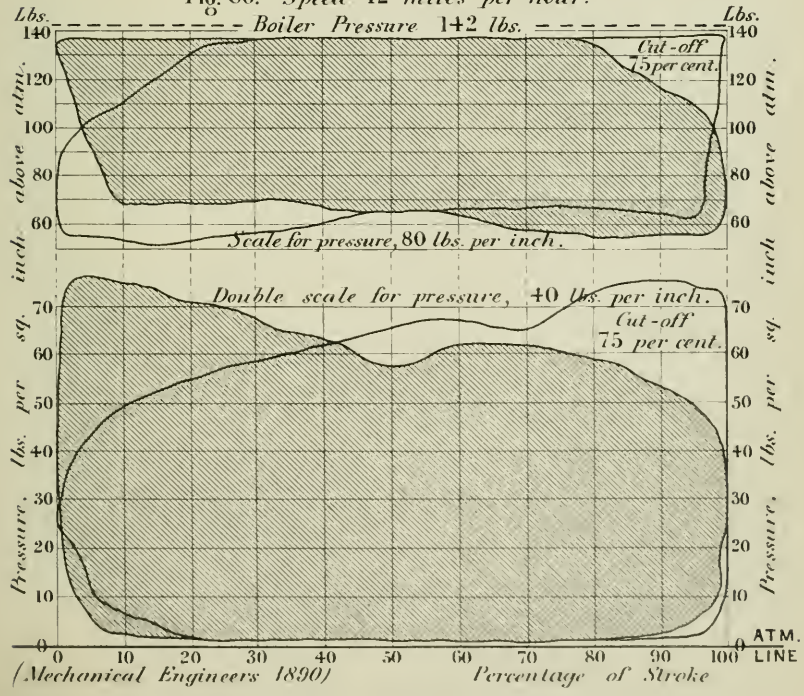

Lbs.
Lbs.
Boiler Pressure 142 lbs.
Cut-off 70 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 70 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100

Fig: 80. *Speed 12 miles per hour.*


Lbs.
Lbs.
Boiler Pressure 142 lbs.
Cut-off 75 per cent.
Scale for pressure, 80 lbs. per inch.
Double scale for pressure, 40 lbs. per inch.
Cut-off 75 per cent.
Pressure, lbs. per sq. inch above atm.
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100
Percentage of Stroke

(Mechanical Engineers 1890)

COAL BURNING ON CAPE RAILWAYS.

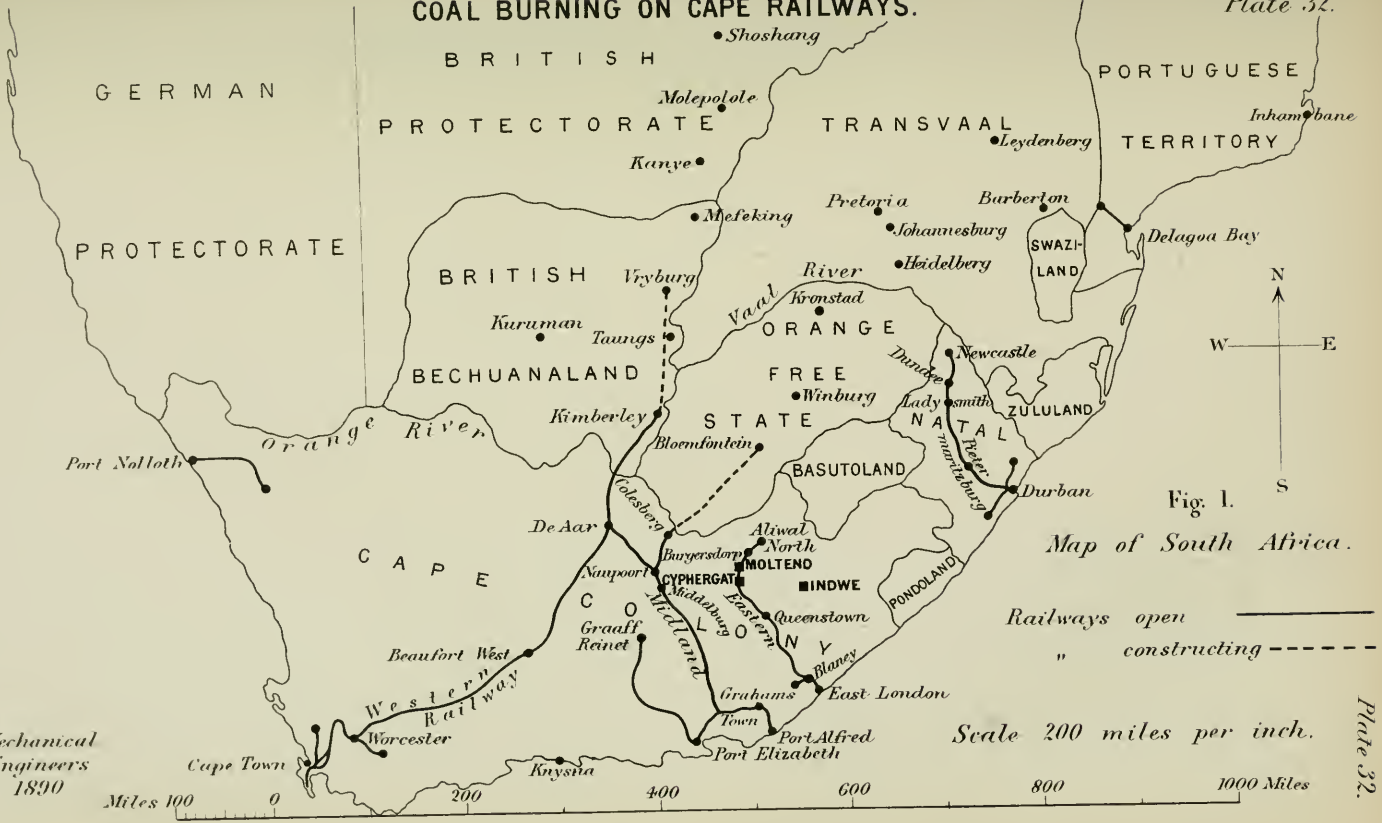


Fig. 1.

Map of South Africa.

Railways open ——————

„ constructing - - - - -

Scale 200 miles per inch.

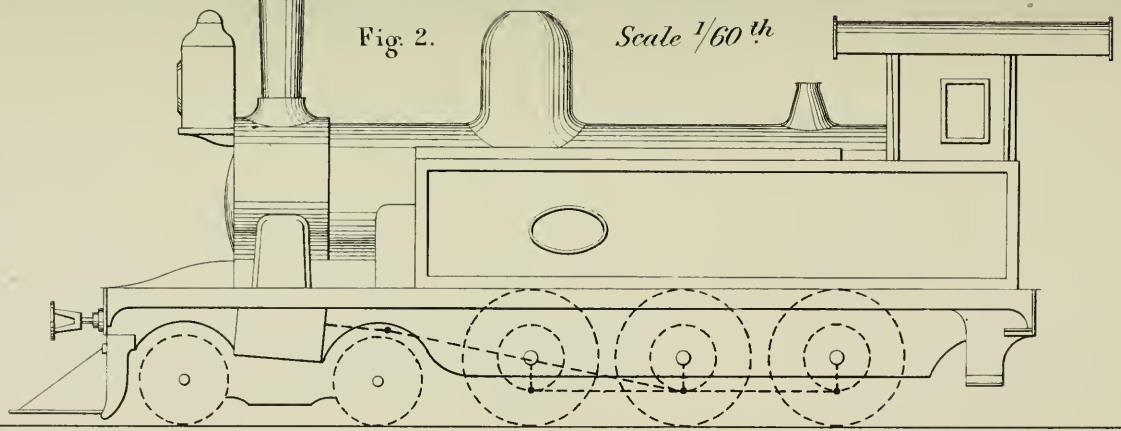
Mechanical Engineers 1890

Miles 100 0 200 400 600 800 1000 Miles

Plate 32.

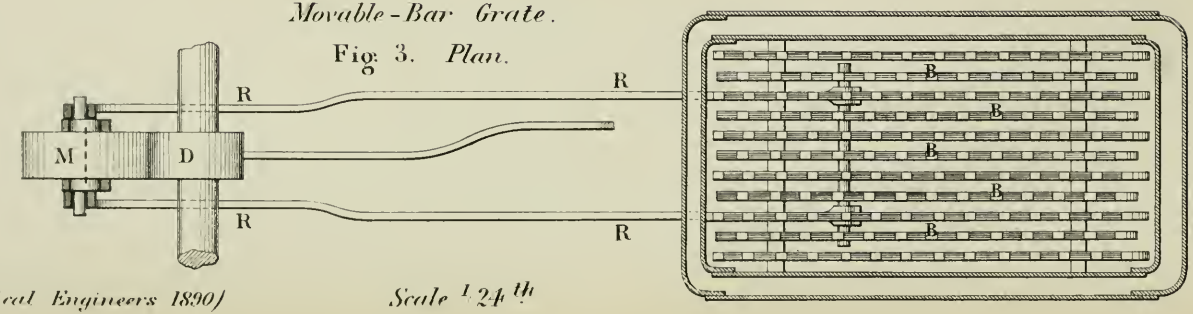
COAL BURNING ON CAPE RAILWAYS.

Fig. 2. *Scale 1/60 th*



Movable-Bar Grate.

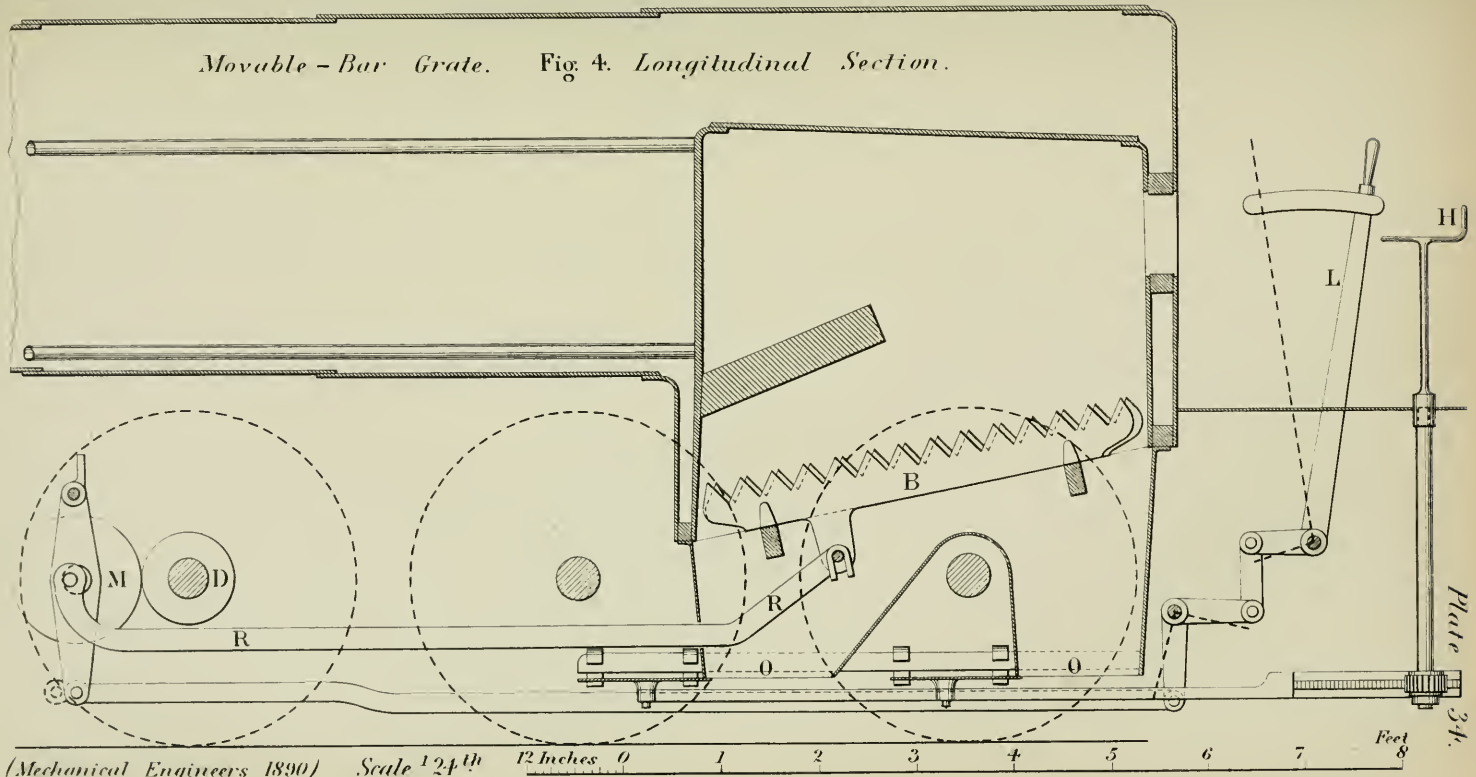
Fig. 3. *Plan.*



(Mechanical Engineers 1890) *Scale 1/24 th*

Plate 33.

Movable-Bar Grate. Fig. 4. *Longitudinal Section.*

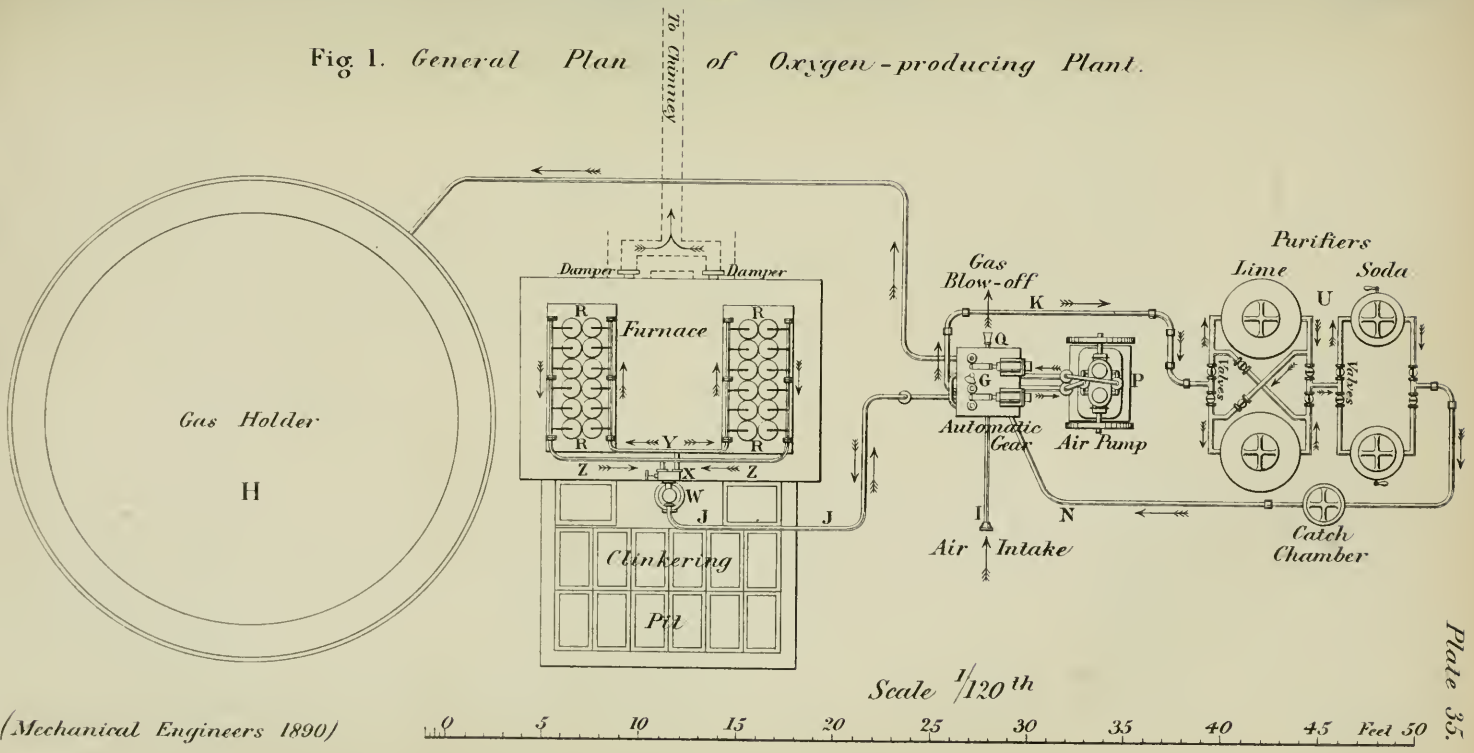


(Mechanical Engineers 1890) Scale 1/24th

Plate 34.

OXYGEN MANUFACTURE.

Fig. 1. *General Plan of Oxygen-producing Plant.*

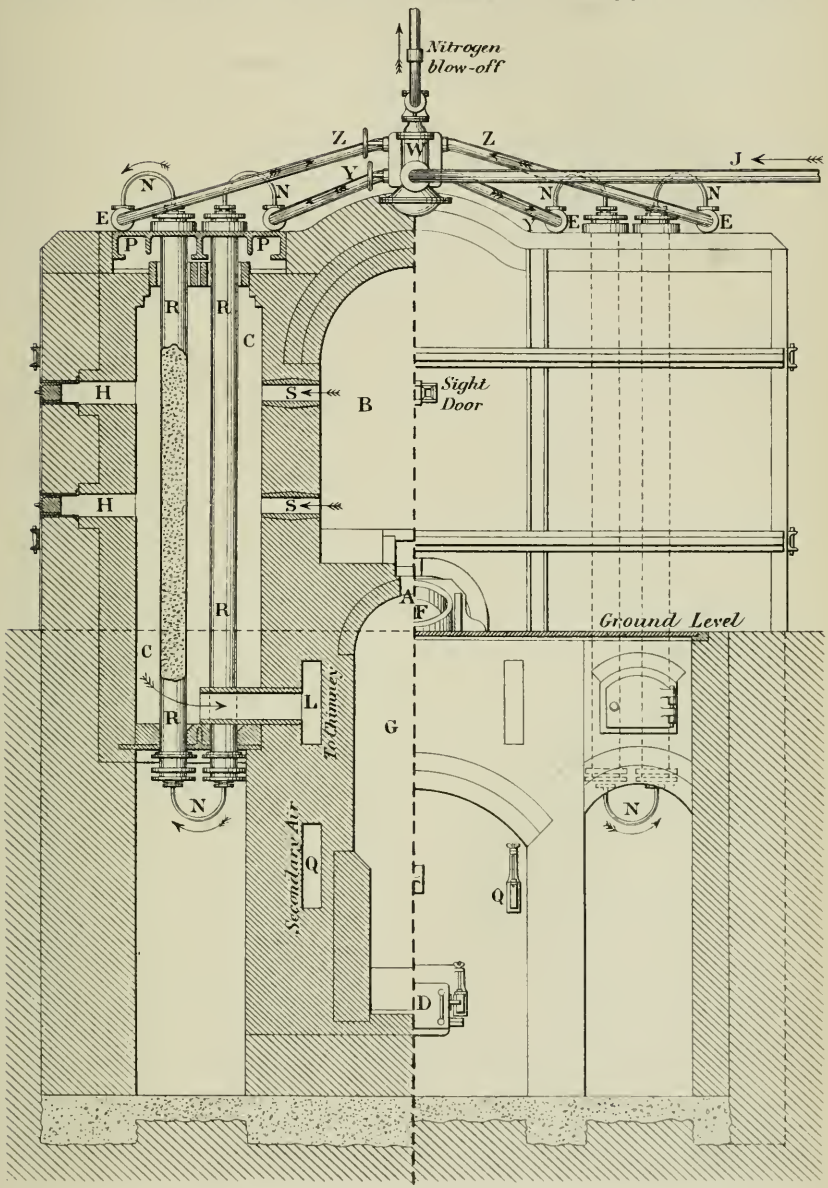


(Mechanical Engineers 1890)

Plate 35.

Fig. 2.

Transverse Section and Front Elevation of Oxygen Producer.



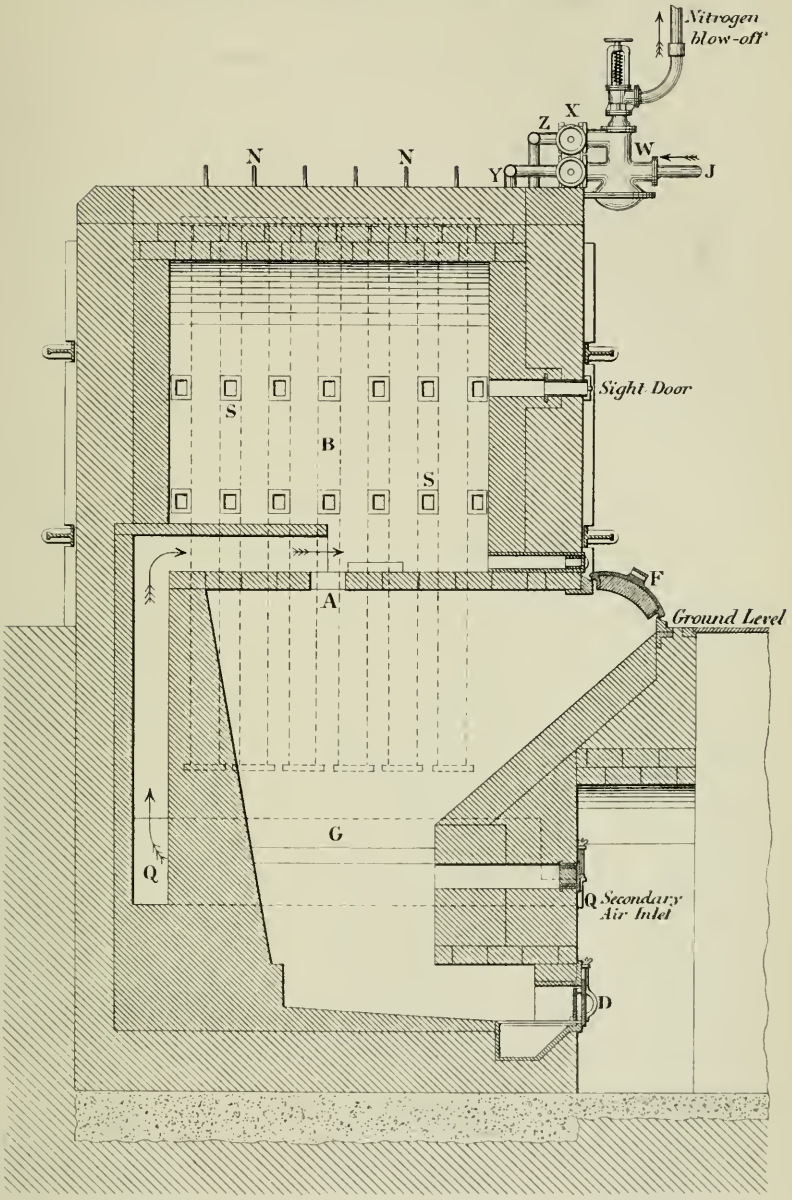
(Mechanical Engineers 1890) *Scale 1/48th*

OXYGEN MANUFACTURE.

Plate 37.

Fig. 3.

Longitudinal Section of Oxygen Producer.



(Mechanical Engineers 1890)

Scale $\frac{1}{48}^{th}$

Ins. 12 6 0 3 10 Feet 15

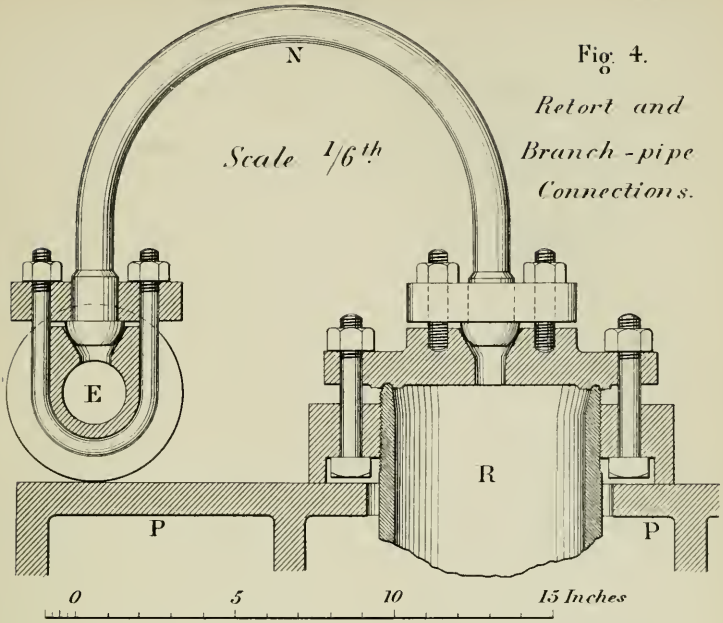
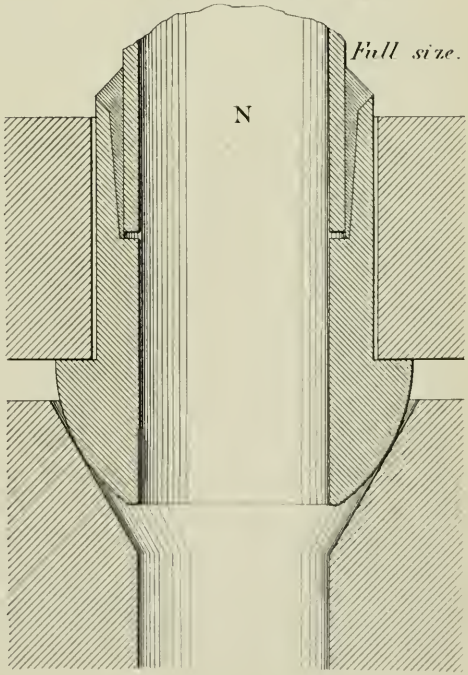


Fig. 4. *Retort and Branch-pipe Connections.*

Scale 1/6th

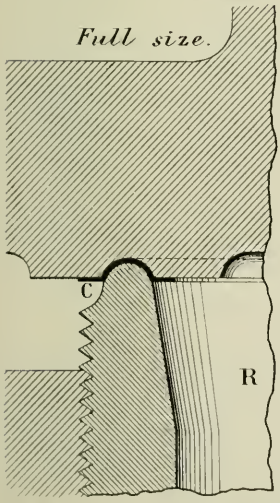
Fig. 6. *Conoid-Conical Joint of bent Connecting Pipe.*



Full size.

Fig. 5. *Section of Joint of Retort Cover.*

Full size.



(Mechanical Engineers 1890)

Automatic Gear and Air-Pump.

Fig. 7. *Elevation.*

Scale 1/32nd

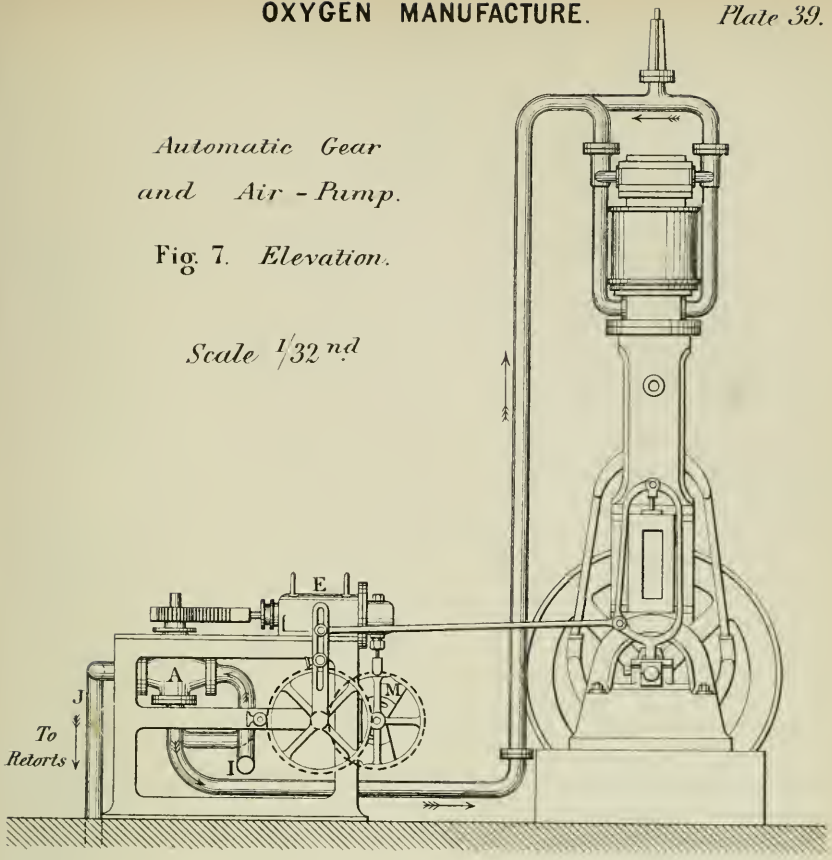
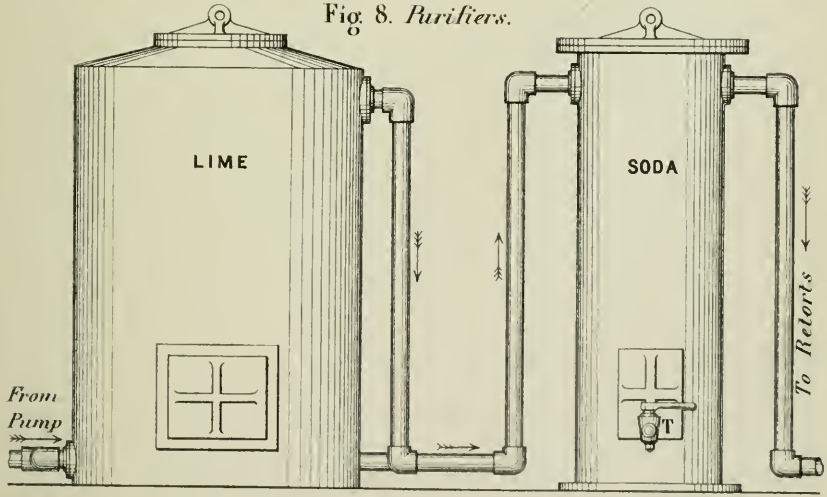


Fig. 8. *Purifiers.*



(Mechanical Engineers 1890)

Scale 1/32nd

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 Feet

OXYGEN MANUFACTURE.

Plate 40.

Automatic Reversing Gear.

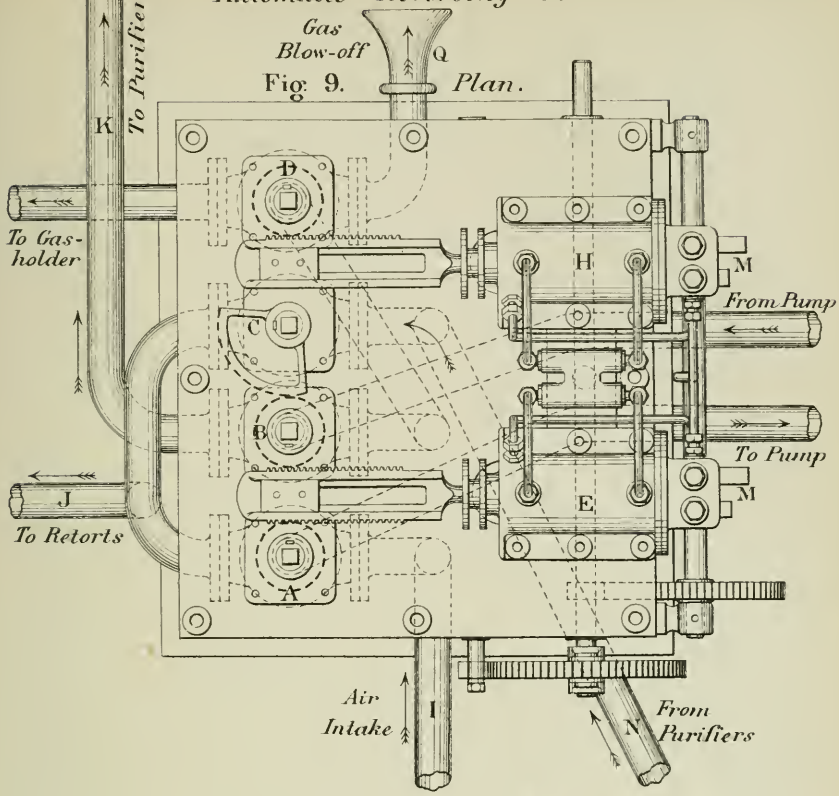
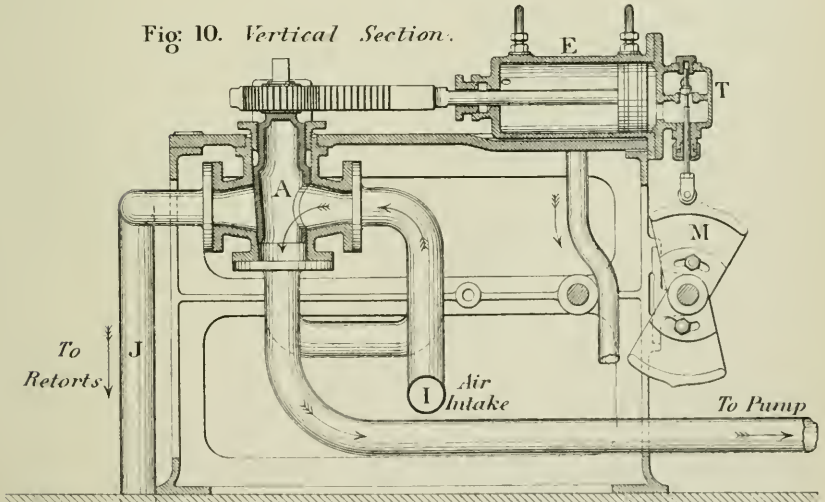


Fig. 9. *Plan.*

Fig. 10. *Vertical Section.*



(Mechanical Engineers 1890) *Scale 1/16th*

Ins. 12 6 0 1 2 3 4 Feet

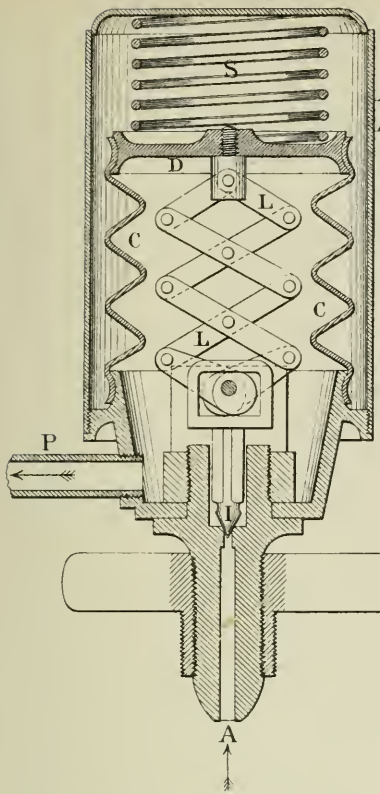


Fig. 15. *Pressure Regulator. Scale half size.*

Fig. 11. *Double-acting Automatic Valves. Scale 1/12th*

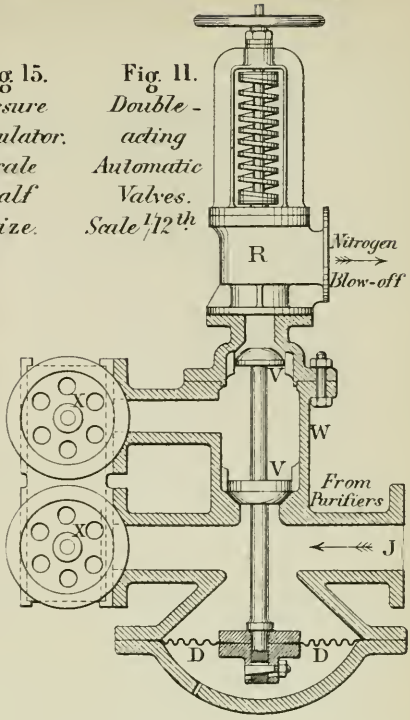


Fig. 12. *Scale 1/6th*
Storage Cylinder

High-pressure Valve.

Fig. 13.

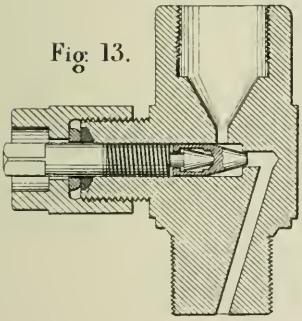


Fig. 16. *Nozzle.*

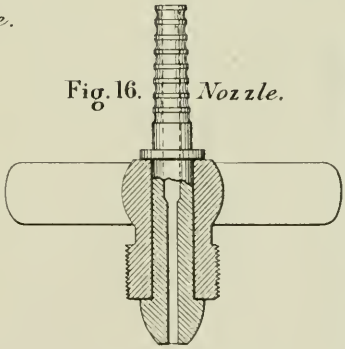
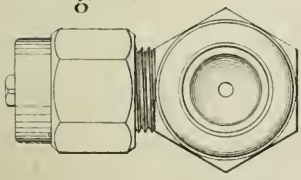


Fig. 14.



Scale half size.

Fig. 17.

(Mechanical Engineers 1890)

Institution of Mechanical Engineers.

PROCEEDINGS.

May 1890.

The Spring Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 1st May 1890, at Half-past Seven o'clock p.m.; Joseph Tomlinson, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that, with the consent of His Royal Highness, the Prince of Wales had been elected by the Council an Honorary Life Member of the Institution of Mechanical Engineers, in appreciation of the interest he had at all times manifested, and the official consideration and recognition he had bestowed, in connection with the works of Mechanical Engineers, as recently exemplified by his opening the Forth Bridge, the latest triumph of Mechanical Engineering.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following twenty-eight candidates were found to be duly elected:—

MEMBERS.

Herbert William Anderson, . .	Halling.
James Eustace Berkley, . .	Secunderabad.
John Blackburn, ...	Bushey.
Henry Robert John Burstall, .	London.
Arthur Cleaver, ...	Sherwood.

WILLIAM CLELAND,	Sheffield.
THOMAS EDWIN CRAVEN,	Leeds.
JOHN GOODMAN,	Leeds.
OSCAR STANDRING HALL,	Bury.
ALLAN HOPPER,	Moscow.
JAMES RUSSELL HOPPER,	Moscow.
SAMUEL EDWARD LEE,	Limerick.
ARTHUR GUY NEVILLE LOCKE,	Boxmoor.
JOHN WALKER LOGAN,	Johannesburg.
CHARLES EDWARD MUMFORD,	Bury St. Edmunds.
KENNETH SUTHERLAND MURRAY,	London.
FRANCIS PEACOCK,	Smyrna.
JAMES ALBERT WELLS PEACOCK,	Smyrna.
WALTER PHILLIPS,	London.
GEORGE HENRY POKE,	Bombay.
SAMUEL RENDELL,	Manchester.
ROBERT ALLEN WILLIAM SWINNERTON,	Ellichpore.
WILLIAM LAWRENCE WILDY,	Leeds.
JOSEPH WILLIAM WILSON, JUN.,	London.
DIGBY CHARLES WINGFIELD,	Dundalk.

ASSOCIATE.

RICHARD CHUBB,	Liverpool.

GRADUATES.

JOHN FREDERICK CLEEVES,	London.
THOMAS REGINALD HATTON,	Birmingham.

The PRESIDENT then delivered his inaugural Address: after which the following Paper was read and partly discussed:—

Research Committee on Marine-Engine Trials: Report upon Trials of three Steamers, "Fusi Yama," "Colchester," "Tartar"; by Professor ALEXANDER B. W. KENNEDY, F.R.S., Chairman.

At a Quarter before Ten o'clock the Discussion was adjourned till the following evening. The attendance was 77 Members and 54 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Friday, 2nd May 1890, at half-past Seven o'clock p.m.; Joseph Tomlinson, Esq., President, in the chair.

The Discussion upon the Report on Marine-Engine Trials was resumed and concluded.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated, shortly before Ten o'clock. The attendance was 51 Members and 48 Visitors.

The Annual Dinner of the Institution was held at The Criterion, Piccadilly, on Wednesday evening, 30th April 1890, and was largely attended by the Members and their friends. The President occupied the chair, and the Guest of the evening was the Right Honourable Sir Michael Hicks-Beach, Bart., M.P., President of the Board of Trade. Invitations to meet him were sent to the Chairmen and principal Officers of the leading Railways in the United Kingdom, as well as to other distinguished Guests; and were accepted by the following, some of whom however were unavoidably prevented at the last from being present.

The Venerable Joshua Hughes-Games, D.C.L., Archdeacon of Sodor and Man; Sir John Fowler, Bart., K.C.M.G., and Sir Benjamin Baker, K.C.M.G., Engineers of the Forth Bridge; Sir Frederick A. Abel, C.B., F.R.S., Honorary Life Member; Mr. J. B. Jackson, Mayor of Sheffield; Mr. S. G. Richardson, Master Cutler; Mr. Henry Kimber, M.P., Wandsworth; Mr. J. W. Maclure, M.P., Stretford; Mr. Courtenay Boyle, C.B., Railway Department, Board of Trade; Colonel F. H. Rich, R.E., Major-General C. S. Hutchinson, R.E., and Major F. A. Marindin, R.E., C.M.G., Inspectors of

Railways, Board of Trade; Mr. Evan C. Nepean, C.B., Director of Contracts, War Office; Mr. W. H. Preece, F.R.S., Electrician, Post-office Telegraphs; Mr. Thomas W. Traill, Engineer, Marine Consultative Branch, Board of Trade.

Kindred Institutions. — Institution of Civil Engineers: Mr. Thomas Hawksley, F.R.S., Mr. James Abernethy, F.R.S.E., and Mr. Edward Woods, Past-Presidents; Mr. William Pole, F.R.SS. L. and E., Honorary Secretary; Mr. James Forrest, Secretary. Institution of Civil Engineers of Ireland: Mr. Spencer Harty, President. South Wales Institute of Engineers: Sir William Thomas Lewis, President. Surveyors' Institution: Mr. Elias P. Squarey, President; Mr. Julian C. Rogers, Secretary. Iron and Steel Institute: Sir James Kitson, Bart., President. North-East Coast Institution of Engineers and Shipbuilders: Mr. Francis C. Marshall, President.

Railways.—Belfast and Northern Counties: Mr. William R. Gill, Secretary. Brecon and Merthyr: Mr. Alfred Henshaw, General Manager. Caledonian: Mr. Archibald Gibson, Secretary. Glasgow and South Western: Mr. James Adam, Engineer. Great Eastern: Captain Daniel Howard, Marine Superintendent. Great North of Scotland: Mr. William Ferguson of Kinmundy, Chairman. Great Northern: Mr. William Latta, Secretary; Mr. Francis P. Cockshott, Superintendent. Great Northern of Ireland: Mr. James C. Park, Locomotive and Carriage Superintendent. Great Southern and Western Railway: Mr. Kennett Bayley, Engineer-in-Chief. Great Western: Mr. Henry Lambert, General Manager. Highland: Mr. Andrew Dougall, Secretary and General Manager. Hull Barnsley and West Riding Junction: Mr. Vincent W. Hill, Traffic Manager. Lancashire and Yorkshire: Mr. George J. Armytage, Chairman; Mr. William Hunt, Engineer; Mr. J. H. Stafford, Secretary; Mr. William Thorley, General Manager. London Chatham and Dover: Mr. John Morgan, Secretary; Mr. William Cockburn, Superintendent of Line. London and North Western: Mr. George Findlay, General Manager. London and South Western: Mr. Charles Scotter, General Manager; Mr. E. W. Verrinder, Traffic Superintendent. London Tilbury and Southend: Mr. H. Cecil Newton, Secretary. Manchester

Sheffield and Lincolnshire: Mr. William Pollitt, General Manager; Mr. Edward Ross, Secretary. Metropolitan: Mr. John Bell, General Manager. Metropolitan District: Mr. George Estall, Resident Engineer and Locomotive Superintendent; Mr. William Jones, Acting Secretary. Midland: Sir Matthew W. Thompson, Bart., Chairman; Sir James J. Allport, Director. Midland Great Western of Ireland: Mr. Martin Atock, Locomotive Engineer; Mr. George W. Greene, Secretary. North British: Mr. James Carswell, Resident Engineer-in-Chief; Mr. G. B. Wieland, Secretary. North Eastern: Mr. C. A. Harrison and Mr. Harold Copperthwaite, Resident Engineers; Mr. Alexander Christison, General Passenger Superintendent. North London: Mr. Oscar L. Stephen, Chairman. Rhymney: Mr. Cornelius Lundie, Traffic Manager and Engineer. South Eastern: Mr. William Wainwright, Carriage and Wagon Superintendent. Southwold: Mr. Arthur C. Pain, Managing Director. Taff Vale: Mr. James Inskip, Chairman; Mr. Arthur E. Guest, Director; Mr. George Fisher, Managing Director; Mr. James Hurman, Traffic Manager. Waterford and Limerick: Sir James Spaight, Chairman; Mr. James Tighe, Engineer; Mr. John T. Murphy, Secretary and Accountant.

Mr. James S. Beale, Honorary Solicitor; Mr. Robert A. McLean, Auditor; Mr. Harry Lee Millar, Treasurer.

Professor T. H. Beare, F.R.S.E.; Professor D. E. Hughes, F.R.S.; Professor W. C. Roberts-Austen, F.R.S.; Mr. A. G. Ashcroft; Mr. Archibald Thomson; Mr. Charles J. Wilson, F.I.C.

Mr. Alexander R. Binnie, Engineer, London County Council; Mr. Walter J. Howell, Board of Trade; Mr. J. Fletcher Moulton, Q.C., F.R.S.; Mr. Christer P. Sandberg and Captain G. Dahlén, R.E., Swedish State Railways.

The President was supported by the following Officers of the Institution: — *Past-Presidents*, Mr. Edward H. Carbutt, and Mr. Jeremiah Head; *Vice-Presidents*, Dr. William Anderson, Sir James N. Douglass, F.R.S., Professor Alexander B. W. Kennedy, F.R.S., Mr. Arthur Paget, and Mr. E. Windsor Richards; *Members of Council*, Mr. Benjamin A. Dobson, Sir Douglas Galton, K.C.B., D.C.L., F.R.S., Mr. Samuel W. Johnson, Mr. William Laird,

Mr. John G. Mair-Rumley, Mr. William H. Maw, Mr. T. Hurry Riches, Mr. Benjamin Walker, Mr. William H. White, F.R.S., and Mr. Thomas W. Worsdell.

After the usual loyal toasts, the President proposed "The President of the Board of Trade," which was acknowledged by the Right Honourable Sir Michael Hicks-Beach, Bart., M.P., who dealt with the relations of the Board of Trade to the Railway and other Engineering interests, to the trading and travelling public, and to the community at large. "The Railway Interest," proposed by Mr. Jeremiah Head, Past-President, was acknowledged by Sir Matthew W. Thompson, Bart., Chairman of the Midland Railway. The toast of "The Engineers of the Forth Bridge" was proposed by Mr. Edward H. Carbutt, Past-President, and was acknowledged by Sir Benjamin Baker, K.C.M.G. Dr. William Anderson proposed the toast of "Kindred Professional Institutions," which was acknowledged by Mr. Edward Woods, Past-President of the Institution of Civil Engineers, and Sir James Kitson, Bart., President of the Iron and Steel Institute. The concluding toast of "The Institution of Mechanical Engineers," proposed by Mr. J. B. Jackson, Mayor of Sheffield, was acknowledged by the President.

ADDRESS BY THE PRESIDENT,

JOSEPH TOMLINSON, ESQ.

Custom now for many years has imposed the duty that your President should deliver an Address; and this duty I am far from desirous of in any way neglecting or attempting to evade, although I feel great diffidence in endeavouring to fulfil it, especially as it will be necessary perhaps to give expression to opinions which it is not open to my hearers to debate and criticise. This fact however is a great relief to myself.

The subject to address you upon was rather a difficult matter to decide; so I began by looking over the records of what had been done by our former Presidents. But after looking over a few of the volumes of our Proceedings, I closed the books, as I was afraid that I might be led into a line of thought not my own; and I put on my considering cap, which developed the idea that the only fitting subject was a kind of *résumé* of my own personal experiences. Therefore, as a railway man of nearly all my working life, I determined that the subject should be principally "Railway Locomotion" of the past and present, with the addition of a few general remarks on engineering subjects of a mechanical nature.

My recollection and practice lead me back to the early days of the locomotive engine, not it is true to the very earliest, although I was born before any public railway was opened. My first knowledge of them as a boy dates back to the year 1837; and I may say that I soon fell in love with a *live engine*, and from then to now have had a feeling of "first love" for it. My father being at the time passenger superintendent of the Stockton and Darlington Railway, it was nothing extraordinary that, with my predilection for mechanics,

my desire to go to the old Shildon Works should be gratified. Mr. Timothy Hackworth, the then locomotive superintendent and also one of the contractors for the working of the railway, was pleased to agree that I should have the "run of the shops"; and thus I began my working life.

The Locomotive Engines in use in the early days of the Stockton and Darlington Railway differed widely in every respect from those of today; and most of the engineers now in practice have but the remotest idea of what curious machines they looked when compared with the creations of the present. Nearly all I daresay have seen old "Locomotion," now on the pedestal in front of the North Road Station at Darlington, Plate 42. This engine was one of three which were first placed on the railway. Two only survived to the time I first knew it. It is now as it was delivered to the railway; but the boiler is not as I knew it at first. When first put to work it would not make steam; and the fire tube had to be taken out and replaced by a return tube, similar to what is now or was until lately the kind of heating surface in the boilers of the north-country class of tug boats. When this had been done, its load was composed of 16 chaldron wagons, weighing empty about 27 cwts. each, or about 22 tons for the train. This was its load from Middlesbrough up the hill to Shildon; and down the hill from Shildon to Middlesbrough it took the same number of wagons loaded, each carrying 53 cwts. of coal, or about 64 tons for the train. The weight of engine and two tenders loaded with coal and water was about 15 tons. There is unfortunately no record of the consumption of fuel [coal] for this early period; but I think I may say, from having helped to put the coal on the tender, that 18 to 22 cwts. were consumed to travel 48 miles, or about 50 lbs. per engine-mile, the principal part of which was consumed on the up-hill journey, as the gradients were at that time all in favour of the load. I need hardly describe this engine, as it is well known. It had two cylinders of 10 inches diameter and 24 inches stroke, half of each being inside the boiler. It had a cross-head to each cylinder, and thus four connecting-rods, and two coupling-rods. It had four wheels of 4 feet diameter

coupled. There were only two eccentrics, which had to be changed in position for back and forward gear, and the engine had to be started by hand-gearing. There was no brake on either engine or tenders. The steam pressure was from 30 to 35 lbs. Necessarily the engine had no springs; and the axles ran in cast-iron plummer-blocks. The pistons were packed with a spun-yarn gasket plaited square, which was tightened by a piece of wood and a hammer whenever required; this was done by the driver and fireman themselves. There was no gauge-glass, and no whistle, a bell being the signal of warning; no hand-lamps or head and tail-lamps, as I shall describe further on. All this was continued for many years.

The next type of engine was the "Royal George," with six wheels coupled, 4 feet diameter, Plate 43. Like its predecessors and many types besides, it had vertical cylinders, of about 11 inches diameter and 18 inches stroke, steam pressure about 40 lbs. The boiler was of the return-flue type, the fire-door and chimney being at the same end. It had two four-wheeled tenders, with ordinary chilled-face wagon-wheels keyed on their axles with wooden and iron wedges. One tender working first up-hill carried the water in one or two large barrels, the driver being on a foot-board at the front end, near the gearing and cylinders; the other tender behind the engine carried coal, from which the firing was done at the back end, see Plates 50 and 51. Like the first engine, this also had only two eccentrics. The leading axle, to which were connected the cylinders, had no springs; but there were springs to the two other pairs of wheels. The engine was carried, like its predecessor, in cast-iron plummer-blocks. The heating surface would be about 120 square feet, not counting the underside of the grate. The load up the hill from Middlesbrough to Shildon was 24 chaldron wagons empty, or about 33 tons; and down the hill the same number of wagons loaded, or 96 tons. The speed both up and down was about 7 to 8 miles an hour.

The next type was, like the earlier engines, made with vertical cylinders, but with a new class of boiler. It had a boiler partly of tubes and partly a flue, of a description similar to what is now used

for small engines, half the length of the boiler having a flue, and then the tubes carried on to the end into a smoke-box. This brought the chimney to the same end as the cylinders. These engines, of which I think there were six, were, as far as I remember, not favourites, and the load had still to be limited to 24 chaldron wagons. Instead of the ordinary wheels of cast-iron, some had wheels made with a cast-iron boss and wood spokes. The tires were of iron, and of the same size, namely 4 feet. The engine too was very much modified. The cylinders were still vertical, but worked on to an independent shaft fitted with cranks, and from thence the power was carried to the wheels by three coupling-rods on each side. The cylinders were about 14 inches diameter and 16 inches stroke. This engine had no slide-bars, the piston-rod being guided by a parallel motion. The principal defect was that, owing to keeping the centre of gravity low, very short connecting-rods had to be used, not more than three lengths of the crank.

The next type was also a departure from the old type in many respects. The boiler was greatly improved, and went by the name of the "Napier" boiler; it had one straight flue for containing the grate, about 9 feet long; at the end was a combustion chamber, from which about 100 tubes came back by the sides of the main flue to the chimney. The steam pressure had also increased to 60 lbs., and the load was increased to 32 wagons, or 44 tons up hill, and 128 tons down. This engine, as will be seen by the photograph, Plate 45, had also no slide-bars, and the piston-rod was guided by a parallel motion. Very short connecting-rods had also to be used. Nevertheless this class of engine was always used to run the passenger trains when any accident or shortness of power rendered it necessary. This engine also had two tenders, and only two eccentrics.

The next type of engine was made with inclined cylinders of somewhat larger diameter and stroke, Plate 50, but with the same size wheels; this enabled springs to be used, and many engines of this class were added subsequently. The boiler was longer, of the return-flue type. This engine took the increased load of 32 chaldron wagons. Like the earlier engines, it had two tenders, one for water and the other for coal, but no brake. The identical engine

"Middlesbro" shown in Plate 50 was not the first engine built with inclined cylinders; the first two were named "Whig" and "Tory," and one of them blew out her flue within a few days of beginning to run.

The wheels of all the classes I have described were of cast-iron, except in the case mentioned with wood spokes, and were made in two parts: namely the boss, which was keyed on the axle; and outside this was a cast-iron ring to take the tire. This ring was secured to the boss by oak filling pieces, as seen in the photographs; and after being wedged tight with steel wedges, the wood was covered by a cap inside and out, and a small bolt was put through to prevent the wedges from coming out. This style of wheel was used nearly to the year 1850, and on some old engines after that date.

I have hitherto spoken only of mineral and goods engines; I now come to the class of passenger engines in use at the time I was a lad. Several of the early engines were somewhat similar to the engines of the Liverpool and Manchester Railway, Plates 48 and 49, on four wheels; one pair of drivers, with 11 to 12-inch cylinders by 16 to 18 inches stroke, and about 4 feet 6 inches to 5 feet wheels. But there was one engine, built I believe by Kitching* of Darlington, which doubtless was never seen by most of the engineers now living. It was called the "Swift," and was of small power, about 10-inch cylinders by 18 inches stroke, with 4 feet wheels coupled, and steam about 50 lbs. The cylinders were vertical between the two pairs of coupled drivers, and worked on to an independent shaft. When I knew it, the trains between Middlesbrough and Stockton were worked with it. It seemed to me subsequently to have been the model from which our late Vice-President, Mr. Crampton, took the idea for his engines of the "Lablache" class, which were put by him in later years on the Great Northern, the South Eastern, and the London Chatham and Dover Railways, though he used a crank-shaft and large wheels and greater power; but the idea of the designer of the "Swift" had doubtless been to take the shocks of working away from the power shaft.

* Mr. George Graham of the North Eastern Railway writes me that this engine was by Hawthorns of Newcastle.

I have now also to describe another engine for passenger train work, designed by the late Mr. Timothy Hackworth, and the only one of its class ever made for England, though a somewhat larger one was made and sent to Russia. This engine, the "Arrow," was the first made at Shildon with what may now be taken as a locomotive boiler, that is, with a fire-box and tubes. The peculiarities of its construction were that it had cylinders of 17 inches diameter by 9 inches stroke, and 5 feet driving wheels. It was a six-wheeled engine with single drivers. It was supplied with a cross-shaft, on which were hung two solid cast-iron wheels. To each end of this shaft a lever was attached, by which the driver and fireman could pull down the solid or friction wheels between the periphery of the driving and trailing wheels, thus temporarily connecting by friction the large drivers and the small trailing wheels: in other words, converting a single engine into a coupled one, when needed by greasy rails. The engine, as will be clearly understood, was a bad starter, and never did any good service. Many years after it was built I happened to be in the North, and enquiring about my old friends I was informed that the "Arrow" was still at work, but that the short crank had been taken out, and a 9-inch put in, and this had been done while still keeping the same cylinders. It was effected by putting in a lever, the top end of which was fixed on the boiler bottom; the piston-rod took hold of the middle of its length, and from the bottom end the small end of the connecting-rod was worked. I need hardly say that such a scheme did not emanate from the brain of Timothy Hackworth, but was, as I heard, the idea of a draper in Darlington.

After this description of the early engines on the parent railway, it will perhaps interest most of you if I describe now some of the peculiarities of how the work was done by the men who were the pioneer workers of railway engines.

In the first place, I will call your attention again to the fact that all the engines up to 1840, including the "Swift" which was built in 1836 or thereabouts, had only two eccentrics, which of course necessitated hand-working to start in either direction. This of itself

required a practised hand to do, and would bother nearly every engine-man of today, inasmuch as, since the abolition of the old "Bury" engine of the London and North Western Railway, that plan has become obsolete.

There was no brake of any kind on engine or tenders, as I have said. The only way of controlling the trains down the banks was to put the engine out of gear, or for the fireman to drop off the engine, and let down as many wagon brakes as he thought necessary; and when they had to be taken off, he had to repeat the operation of getting off and lifting them, he himself then getting on the last wagon of which the brake had been down, and walking along the top of the coals back to his engine.

In my early days the engines were worked by contract by the driver, who found coal, oil, and every requisite, and was paid per ton of coal moved. The "driver" had two men in his pay, one a "driver-fireman" and the other a "fireman." The steam was got up on Sunday night by the fireman; and the driver and he ran the first train on Monday morning (as early as coal was there to take) from Shildon to Middlesbrough, the then port of shipment. On the return to Shildon in about eight or nine hours, the fireman went home, and the driver with his "driver-fireman" ran the second trip; and on the completion of the second trip the "driver" went home, and the "driver-fireman" took charge as driver, and the "fireman" who had been resting resumed duty as fireman, and this system was followed day after day. No trains were run on Sunday.

The other duties of these men was somewhat as follows:—on the return after a trip the engine was taken to the coal depot, and coaled with a shovel by the men themselves ready for the next trip. If traffic was plentiful the stay was short, and after a meal the engine was off again. There was no time-table. After going about a mile from Shildon all the wagons had to be oiled, as there were no grease boxes; the engine was slowed down on the level to about three or four miles an hour, and the two men got down, one on each side, with his oil-can and a hazel stick about three feet long, at the end of which a piece of oakum was tied; and with this the underside of each journal running in a cast-iron plummer-block was carefully

oiled. After all were done, they got on the top of the last loaded wagon and walked back to the engine, and away they went. This was repeated after about twelve miles, when going in both directions. There was no guard and no brake-van, and so all depended on themselves. As there was no van, it was necessary in the day-time to put a board up on the last wagon, so as to be sure they had not lost any of the train. At night a large pan of fire was affixed to the front of the tender and to the last wagon for the same purpose; and it was the duty of the fireman to keep both alight. There were no signals and no pointsmen, each man taking care of himself and his train, and keeping out of the way of the few passenger trains run.*

In page 189 is shown a facsimile of an original time-table of the passenger trains run on week-days in 1836 on this railway, and you will see it is all on a sheet not larger than a page of note-paper. No passenger trains were run on Sundays, except between Darlington and Stockton once each way, which were worked by a horse. The carriage was on four wheels without springs, and was made to carry six inside and fourteen outside, including the coachman. It was like an old ordinary road "stage coach" with two front ends. The ordinary passenger trains on week-days had one first-class with three bodies, which could carry eighteen passengers; and one second-class, also with three bodies, which could carry twenty-four passengers; these two were attached at Darlington to the train which came from Shildon, and were

* Mr. George Graham of the North Eastern Railway, manager of the North Road Engine Works at Darlington, to whom I sent a copy of my address, writes me as follows:—"You may remember a driver named George Sunter. This man used to run a train of wagons from Shildon to Middlesbrough without stopping, and his engine would take water at both Darlington and Yarm. To do this he uncoupled his engine from the wagons about a mile before arriving at each place, ran it forward, took in water, started his engine, and coupled up to his train when the wagons were still running." What would locomotive engineers and traffic managers think of this today? He also adds: "Something may be said about the great quantity of red-hot cinders" (query coal?) "which used to be pitched out of the chimneys. This you will know was on account of the small size of the blast-pipe, and only a return flue, and with no small tubes: which might be described as a moving fire-works at night."

SUMMER OF 1836.

STOCKTON & DARLINGTON RAILWAY

COACHES.

INCREASED ACCOMMODATION.

Separate Engines having been appointed for the Conveyance of Passengers and Merchandize, and a Coach attached to the latter Train, the Opportunities of Communication between the Towns of Darlington and Stockton are doubled, and between Darlington and Shildon they are now four times a day.

DARLINGTON & ST. HELEN'S AUCKLAND TRAIN.

Fares: Inside, 1s. 6d.—Outside, 1s. 3d each way.

STATIONS.	TIMES OF STARTING.	STATIONS.	TIMES OF STARTING
From Shildon, at -	5 o'clock.	From Darlington, at -	half past 8 o'clock
St. Helen's Auckland	quarter bef. 7 "	Do - -	half past 1 "
Do. - -	11 "	Do. - -	half past 5 "
Do. -	quarter bef 4 "	Do to Shildon -	8 "

From the LANDS at a quarter past 6 in the Morning, and from DARLINGTON to the LANDS at half past 5 in the Evening,

N. B. The Train will leave Shildon half an hour after leaving St Helen's Auckland A CAR from Bishop Auckland to St. Helen's or New Shildon, meets each of these Trains in going and returning.

Fares to Shildon: Inside, 1s.—Outside, 9d

DARLINGTON AND STOCKTON TRAIN.

First-class Fares: Inside, 2s.—Outside, 1s 6d, each way.

Second-class, or Merchandize Fares: Inside, 1s. 6d.—Outside, 1s, each way

* From Darlington,(Merchd.) at	half past 6 o'clock	From Stockton, at -	quarter past 7 o'clock
Do. - -	half past 8 "	Do (Merchandize)	9 "
* Do. (Merchandize)	11 "	Do - -	quarter bef. 12 "
Do. - -	half past 1 "	Do (Merchandize)	1 "
Do. (Merchandize)	3 "	Do - -	quarter past 4 "
Do. - -	half past 5 "	Do. (Merchandize)	half past 6 "

On MONDAYS and WEDNESDAYS, a Second class, or One Shilling Carriage, will accompany the First-class Coach Train.

STOCKTON AND MIDDLESBRO' TRAIN.

Fares: Inside, 6d.—Outside, 4d., each way.

From Middlesbro' at	-	half past	6 o'clock	From Stockton, at	-	half past	7 o'clock
Do	- -	half past	8 "	Do.	- -	half past	9 "
Do.	- -		11 "	Do.	- -	half past	11 "
Do.	- -	half past	12 "	Do.	- -	half past	1 "
Do	- -		2 "	Do	- -	half past	2 "
Do.	- -	half past	3 "	Do	- -	half past	4 "
Do.	- -		6 "	Do	-	half past	6 "
* Do.	- -		7 "	Do.	- -	half past	7 "

All the Darlington and Middlesbro' Trains are in immediate connexion with each other, excepting those marked thus *

The MERCHANDIZE TRAIN will be allowed from One and a Half to Two Hours between Darlington and Stockton, whilst various applications having been made by Gentlemen in the Neighbourhood, to have the Coach Trains expedited and improved, Arrangements have been made to run the Darlington and Stockton Trip in FORTY FIVE MINUTES, a New Engine and Outside Coach are provided, and the Fares now charged for this Class are consequently about on the par of other Railways.

All PARCELS (requiring haste and care), are to be left as under:—

THOMAS REYNOLDS, Angel Inn, Bp Auckland	JAMES TURNER, Northgate, Darlington
J COXON, St Helen's Auckland	GEORGE PEACOCK, Majestic Office, Stockton
R. THOMPSON, New Shildon	JOHN UNTHANK, Middlesbro'

General Merchandize for all Parts of the Kingdom, to R. ROBINSON, Merchandize Station, Darlington

Railway Office, Darlington, March 4th, 1836.

Coates & Farmer, Printers

put off at the junction at Stockton. The engine coming from Shildon brought a composite carriage with one first-class and two second-class bodies, or twenty-two seats, which was run on to Middlesbrough. The speed averaged about 16 miles per hour. The whole journey was 24 miles.

One engine not already described, which was also put on the old line, was the first goods engine with a crank-shaft, a fire-box proper, and a tubular boiler. It was built by Kitching of Darlington about 1838, and was called the "Queen." It had four wheels only, with cylinders below the level of the axles and inclined upwards, 13 inches diameter and 18 inches stroke, and outside frames. All the wheels were coupled, and were the first that were constructed of wrought-iron. This engine was very similar to engines made about 1839 and 1840, and put on many other railways, but with a pair of small wheels added behind; and the same class thus modified was used for five or six years on nearly all the lines in England.

The Clarence Railway, which is now, like the Stockton and Darlington, a part of the present North Eastern, had mineral engines at starting very similar to those I have described, and of which I show all that can be got of them in photographs. This line ran from Coxhoe to Port Clarence, with a branch to the old line, and was a rival to it; and hence any coal from Shildon to Simpasture, the junction, had to be worked by horses, as it had no running powers, and the Stockton and Darlington would not supply engines. Four wagons were drawn by one horse; and there was attached to the end what was called a "dandy cart," into which the horse was trained to put himself when the loaded wagons would run by gravity.

The first outside-cylinder coupled engine ever made with horizontal cylinders was put on this Clarence line, and was built by Hackworth and Downing at the Soho Works, Shildon. This Hackworth was a brother of Timothy, and afterwards started with Mr. Fossick the works at Stockton now known as "Blair's." The engine had the usual return-flue type of boiler, with six wheels coupled, and cylinders of 13 or 14 inches diameter and 20 or 22 inches stroke. Up to this time all the mineral engines were innocent of framing, as it is now understood; all the parts for doing

the work of drawing and carrying were attached to the boiler, and hence all were as light as could be made.

About the time I first began to work, a stir was being made in the matter of railways, and several were almost simultaneously opened in England:—the Manchester and Leeds, the Great Western, the London and South Western, the London and Birmingham, the Derby and Birmingham, the Birmingham and Gloucester, the Gloucester and Bristol, the North Midland, the Grand Junction, the Midland Counties, the Eastern Counties, the York and North Midland, the Greenwich, the Croydon (atmospheric), the Blackwall (rope), &c., &c.

All the various locomotive superintendents of that day having had the experience to study of the three parent lines—the Stockton and Darlington, the Clarence, and the Liverpool and Manchester—it was not strange that many variations should be introduced, which it would be impossible to describe in detail in such an address as this. Sufficient to say that some, like Bury, adopted four-wheeled engines with inside cylinders; some, like Alexander Allan, John V. Gooch, and Francis Trevithick, adopted outside cylinders; some had small drivers, and some had large; but all of them adopted, like Allan, single drivers for passenger trains, and for many years all adopted four wheels coupled for goods.

We have now arrived at 1841 to 1842, when railways had assumed proportions never dreamt of by the early pioneers and engineers, and the work was done by different types of engines, according to the ideas of the different men who had the control. The various designs, and who were the designers, and which was best, formed the subject of constant letter-writing and paper war. An especially notable case was between the firm of Bury and Co. and those who advocated six-wheeled engines; but to go into this is no part of my task, neither is it to write about the discussions between George Stephenson and Timothy Hackworth as to the invention of the blast-pipe, and between George Stephenson and William Hedley as to who invented the locomotive. All honour, say I, to all who in any way assisted the beginning of what has developed into the present system, and

who unwittingly have done more to civilize the world than any other pioneers.

One of the greatest moves in a progressive direction was made about the year 1845, when the battle of the gauges was fought, and when gigantic efforts were made by all to outvie one another—Stephensons, Hawthorns, Bury Curtis and Kennedy, Sharp Roberts and Co., Fairbairn, Fenton Murray and Jackson, E. B. Wilson, and others. Of those in charge of locomotive departments, like James Edward McConnell, Daniel Gooch, James Cudworth, John Viret Gooch, Alexander Allan, Francis Trevithick, Matthew Kirtley, Thomas Russell Crampton, and many more, most have now passed away from the scenes of their labours. We have one notable instance of a man left to us today who took part in these early struggles, and I am glad to say is still active and well, I mean Mr. Edward Woods. Another still with us, but retired, is Mr. Alexander Allan, my old chief.

The revolution in size of engine was then begun, with great diversity of design, and against all sorts of difficulties, chiefly those arising from want of endurance of material in rails and tires; and was carried on at all costs till the age of Sir Henry Bessemer, followed by Sir William Siemens, who together gave the power to advance boldly and introduce engines of greater power and endurance than was possible before, when the endeavours of all locomotive engineers had been directed to keep down weight, and at the same time to construct machines that could do the work demanded of them. The relief came by the success realised in making durable, strong, and reliable material, which enabled the railway engineers to carry out their views, and to make the rolling stock what it now is, whereby speeds can be safely attained and loads taken which would have seriously disturbed the minds of our predecessors; while still a profit is left after providing the increased accommodation demanded by the ever-exacting public. The details of what is now being done can be compared by you all with what I have spoken of as the early working of railways, and therefore I need not attempt the comparison. The creations of today are the work of many engineers, including Matthew Kirtley, Daniel Gooch, Alexander Allan, Francis Trevithick, James

Edward McConnell, John Viret Gooch, Edward Fletcher, John Ramsbottom, Joseph Armstrong, Charles F. Beyer, Henry Dübs, Walter Neilson, Samuel W. Johnson, Patrick Stirling, Charles Sacré, William Adams, Francis W. Webb, William Kirtley, William Stroudley, Dugald Drummond, and many others who are well known.

Having given as clearly as I could an account of the early locomotive engine, and not attempted to go into details of what has been done during the last twenty or twenty-five years, which has been so fully and forcibly shown by innumerable publications, and so clearly illustrated by the aid of photographs, I do not purpose to add more, except to make a few general remarks in order to show by a few examples how in a locomotive engine, as in other things, history has repeated itself.

The first example I will give is the bogie. Every modern engineer I think would say that this part of an engine, in its most simple form, was first adopted by Mr. Daniel Gooch in the engines built about the year 1848 for the South Devon Railway, as detailed in Mr. D. K. Clark's volume on Railway Machinery; and this plan was afterwards adopted by Mr. Pearson for his ten-wheeled express engine on the Bristol and Exeter Railway, and by others. That is not so however; for the earliest bogie, in this country at least, was on an engine built by Carmichael of Dundee in 1833 for the Dundee and Newtyle Railway, of which a photograph is shown, Plate 46. The old engine was found by Mr. Alexander Allan when he was locomotive superintendent of the Scottish Central Railway about 1855; and before it was broken up it was photographed.

Next we come to the radial axle-box as used by Mr. Webb, Mr. Worsdell, and others. This was invented without doubt by the late Mr. William Bridges Adams, and was applied by Mr. Cross on the St. Helen's Railway in an exactly similar way to what Mr. Webb and others are now doing. The engine was called the "White Raven," and was on eight wheels like Mr. Webb's, the two end pairs of small wheels being free to move radially. I need not say it was by no means so perfect as it has been made at Crewe and

copied by others. The fact of the modern engine having inside bearings has greatly facilitated improvement and the making of a compact and useful design.

To the use of an intermediate shaft for the first power in the old "Swift" I have already alluded.

The position of the frames has also passed through many changes, beginning with inside and then to outside, and then backwards and forwards from one plan to the other; until at last it has become almost universal that they should be inside, although in his last design of single engine Mr. S. W. Johnson has once more come to the outside and inside frame combined, Plate 85, as was for so long generally adopted. This double frame has undoubtedly the merit of enabling less weight to be carried by each square inch of bearing surface of the journals.

Now to come to design of engine. In 1851 Mr. McConnell put on the London and North Western Railway a class of engine called "Bloomer," Plate 61, which is without doubt exactly similar in general design to those made by Mr. Stroudley and known as the "Grosvenor" class, the only difference being that the latter designer was not hampered as Mr. McConnell had been by the necessity for keeping down the weight. Some of these engines are still, after thirty years, doing useful duty on the North Western Railway.

The battle of the gauges brought to the front various types of engines. Every engine builder and locomotive superintendent made the greatest possible efforts to do something, and sometimes with conspicuous success. In 1846 Mr. Daniel Gooch produced his "Great Britain," of the same type as the "Lord of the Isles," shown in the photograph, Plate 56; and this class of engine I think may be regarded as one of the most successful, for it continues to this day in its original form down to the minutest detail, and now working all the broad-gauge expresses between London and Bristol. New boilers these engines have had, and a higher pressure of steam has been the only change. The express is run now, though of much greater weight than in 1846, at precisely the same speed, namely 53¼ miles per hour between London and Swindon.

Stephenson and Co. also came to the fore with the long-boiler type and outside cylinders; the drivers of the single engine being placed in front of the fire-box, and two pairs of carrying-wheels leading.

Mr. Crampton too added his contribution in the shape of the "London" and "Liverpool," both of them with the driving wheels behind the fire-box and the carrying wheels in front, and with outside cylinders placed about midway along the barrel of the boiler. This class of engine was largely used on the Western of France and the Northern of France, and some survive today. A photograph of a drawing is given in Plate 54.

Mr. Francis Trevithick produced at Crewe the "Cornwall," with 8 feet single drivers, 18-inch cylinders and 24 inches stroke. To keep the centre of gravity down, the boiler was placed wholly under the driving axle: which plan necessitated that the axle of the trailing wheels should pass through the fire-box. It was not a good engine for steam, and about 1863 was supplied with a new boiler above the driving axle, Plate 58; and it is thus working at the present time. It is now forty-three years old, and is kept up, I suppose, for sentiment, as it cannot do main-line work.

Mr. John Viret Gooch too had a special engine made for the London and South Western line, with outside cylinders and 7 feet drivers, which did useful work for years; but he was tied in weight by the lightness of the road.

Sharp Stewart and Co. constructed engines of large power for those days, which went by the name of "Jenny Sharp." They had 16 × 22-inch cylinders, with 5 feet 6 inches single drivers, and inside and outside frames, and were very successful engines. They were from the design of the late Mr. Charles Beyer.

E. B. Wilson and Co. of Leeds produced an engine which was called "Jenny Lind," Plate 60. Of this class many scores were built; they had 15 × 20-inch cylinders with 6 feet driving wheels. The drivers had inside bearings only, and the leading and trailing were 4 feet wheels with outside bearings. They were largely used in the north, and as far south as Rugby on the Midland. These engines were principally designed by the late Mr. James Fenton.

I could go on to almost any extent; but I think, as I have now got to a period when many others can give their experiences, I shall desist. I have done my best to render my address interesting at any rate to those of our members who are not old enough to know of what our early times consisted. Today all is smooth sailing; a good road and strong good material to work with, and plenty of information to guide those who shall come after us; and therefore I shall here bid good-bye to the locomotive engine, with the hope that the pleasure I have derived from its study, its erection, and its working, may be enjoyed by all those who love their work as I have done through life. I cannot close however without acknowledging with all sincerity the assistance that the writings of my old friend Mr. D. K. Clark have been to me; and I will add that students of railway locomotion will not find among all who have written on this subject a more faithful guide. I call Mr. Clark my old friend, because I did my best to assist his investigations more than forty years ago, when from lack of age and experience I was unable to realize the ultimate value of his research. From Zerah Colburn too I must confess to having learned much.

The Railway itself as a road, like the engine of which I have treated, has undergone in the course of years a considerable alteration and improvement; but the change cannot be called so radical as in the engine. The rails of which the pioneer railway was made at my time were of wrought iron, in about 15 feet lengths, and about 35 lbs. per lineal yard, carried on very small cast-iron chairs, which were secured either to stone blocks or to light sleepers of larch timber, many of them of half-round section. The rails were of fish-bellied type, and the ends were a sort of half lap, about 2 inches long. They were secured in the chairs with a round cast-iron ball of about 1 inch diameter, held in by a wrought-iron key about $\frac{3}{4}$ inch square, which was bent to prevent its coming out; there were no wood keys in those days. In a few years a parallel rail with a small bulb bottom was rolled. This soon gave way to a double-headed rail, which held its own for many years, and until 1870 was, I may say, the standard,

and at last was increased to 84 and 90 lbs. per yard, and rolled of the section known as "bull-head."

In the interval the form called the bridge rail was brought out, similar to the rail used on the Great Western for the broad gauge; and this, increased in weight, is still used. About thirty-five years ago a rail, which was to dispense to a great extent with sleepers, was designed by Mr. W. H. Barlow; but the road was hard and not lasting, and it was soon discarded. Some of the Welsh railways, notably the Newport and Abergavenny, were laid with it, as was also the Birmingham and Derby. About the same time the Vignoles rail was produced, and a great deal of road was laid with it; but after some years it was practically given up in England, except for light branches and for contractors' use. Foreign nations and America took it up however, and it is now almost the only rail used. By the perseverance of Mr. C. P. Sandberg, who came over here as the inspecting engineer of the Swedish and Norwegian Governments, it was re-designed in detail, until it has now reached a weight of 105 lbs. a yard. We in England have gone on increasing the weight of the rail to meet the greater weight of engine, and have added sleepers in proportion until 2 feet 6 inches to 2 feet 8 inches is now their distance from centre to centre; but some of our foreign neighbours, notably the Germans, are still a long way behind us, notwithstanding they have equalled us in the weight to be carried on a pair of wheels.

Wrought-iron and steel are gradually replacing the old cast-iron arches throughout our country. The earliest wrought-iron bridges of long span were certainly not handsome, though strong: notably the Menai, the Chepstow, the Saltash, &c. But the latest and the greatest ever made in the world, across the Firth of Forth, by Sir John Fowler and Sir Benjamin Baker, is not only enormous in size, but, now it is finished, looks a graceful structure, and in my mind is the greatest work ever executed in this or any age. The bridge of Mr. Barlow, to replace the ill-fated bridge across the Tay, is also a beautiful piece of mechanical engineering. The fall of the old bridge and its consequences point a moral to all future engineers,

and it is this:—do not let others ever cause you to deviate from true principles, or allow them to persuade you to let mere money be the guide as to strength in your work. If Sir Thomas Bouch had not been influenced by such means, he would not have built the bridge he did, and his bridge would be across the Tay today, and he might in all probability have been living now. While on the subject of bridges, I cannot help the remark that Brunel's bridge across the Thames at Maidenhead has always been admired by me as the most graceful I ever saw. The high-level bridge of Mr. T. E. Harrison at Newcastle must not be omitted from this record, for at the time it was erected it was ahead of everything, and still stands as good as ever.

To look back to former times and to think that on early lines there were no station buildings, and then to turn to the structures now existing, is sufficient in itself without comment; and when we consider that so many of them, except in respect of being enlarged, are almost of the design of the original engineer, they are something to be proud of, both as mementos of foresight and as tokens of progress.

To illustrate the progress of the Locomotive Engine from early times to the present, there is shown in Plates 42 to 86 a selection of photographs, presenting I hope a fairly good idea of the advances made from time to time, and giving about the date that the first of each class was constructed, with the name of its author or designer.

The President exhibited an extensive collection of engravings and photographs of locomotive engines, illustrating their progressive development as traced in the address. Amongst other curiosities were two facsimile reprints of "Bradshaw" for the year 1839, showing what railways were opened at that time and what were about to be opened. For certain lines there were tables left blank without any figures; they were put in blank because it was expected that the lines were to be opened some day. Another time-table was that of the London and South Western Railway, which showed on a single sheet all the trains running on that line in 1852, both up and down; all these figures had been arranged by himself, now nearly forty years ago. He showed also a map of the county of Durham, published in 1840, from which it could be imagined what changes must have taken place in the north of England since the time when he was there as a boy.

Mr. Edward H. Carbutt, Past-President, proposed a vote of thanks to the President for his very interesting Address. He had the pleasure of remembering that he had now known the President ever since 1854, when they had been together on the Midland Railway. Mr. Tomlinson was then in charge of the sheds in the running department, and he himself was in the shops and in the drawing office. He used often to hear from him in those days about his earlier locomotive experience on the Stockton and Darlington Railway and his work in connection with Mr. D. K. Clark. He had always looked upon him as an enthusiast; and it was certainly his enthusiasm which had caused him to stick to locomotive work through his life. The account which he had now given of his experience would be very valuable to the younger members of the Institution. The present year would be memorable as essentially a locomotive year for the Institution; at the dinner yesterday evening there had been present the locomotive superintendents of most of the principal railways in the United Kingdom; and although unfortunately many of them were so busy that they could not be present now to have the

(Mr. Edward H. Carbutt.)

pleasure of listening to the President's remarks, he was sure that when they read his address they would be pleased that he had put on record all his recollections of what had taken place on the Stockton and Darlington Railway, with which he had been connected so many years ago. Many of the Members would be rather astonished to learn from the address how difficult it had been not only for the engineers but for the working men to conduct the traffic in those early days; and it was a happy thing for all that the times were now so much easier for them. The hours of work were now shorter and the pay better than in those early days. A great deal of the improvement was due to the locomotive engine and the railway system. After the experience he had gained on the Stockton and Darlington Railway, the President had been on the London and South Western, on the Midland Railway, on the Taff Vale, and on the Metropolitan Railway. There was therefore hardly anyone in England with a more extensive locomotive experience; and the value of his address was enhanced by the admirable collection of photographs with which he had illustrated his remarks, and by the antiquated time-tables which were curiosities in themselves. The Members he was sure would all agree that they were much obliged to the President for the trouble he had taken, and would thank him heartily for the address which he had delivered.

Dr. WILLIAM ANDERSON, Vice-President, in seconding the vote of thanks to the President for his valuable Address, said he had been much amused by the description of the way in which railways had been worked in those early days, because there was a railway which was worked in the same way at this moment; that is to say, the drivers had to get off the engines, in order to set the points, and sometimes in order to apply the brakes. The railway had an aggregate length of nineteen miles, and it had thirty-seven locomotives, which ran at a pretty good speed; and both the locomotives and the rolling stock presented nearly as much variety as the photographs here shown. The railway was not far from London; it was at the Royal Arsenal, Woolwich, and was an example of how traffic could go on without rules or time-tables. The locomotives were curiosities in their way; nearly every form

of light locomotive that had ever been devised for the 18 inch gauge and for the 4 ft. 8½ ins. gauge had a representative at the Royal Arsenal; they formed indeed a very interesting collection. Still, they did their work very well; and it was a curious thing at the present day to find that the traffic could be conducted under such circumstances. It had at last been decided however to appoint a traffic manager and draw up a time-table, and work the line according to some sort of rules; and therefore the present state of things would not continue much longer. The experience which the President had recorded in his address was such as could be recalled by very few men now: indeed he doubted whether anyone, except Mr. Edward Woods, Mr. Alexander Allan, and one or two others, could recall so many curious points in connection with early railway practice. The address had been highly interesting, and he was sure all would join in the vote of thanks which had been proposed.

Mr. T. HURRY RICHES, Member of Council, in supporting the vote of thanks, said that it afforded him the greatest pleasure to see his old chief in the proud position of President of this Institution. Having served his time under Mr. Tomlinson, and been associated with him more or less from his earliest connection with engineering, he was very glad to take this opportunity of saying how sincerely he congratulated him on the position he had attained; and he trusted the Members of the Institution would for many years continue to enjoy the advantage of his presence amongst them.

The vote of thanks for the President's Address was passed with applause.

The PRESIDENT thanked the Meeting for the kind way in which they had acknowledged the address. Having for thirty-three years been a Member of this Institution, he had throughout taken all the pains he could to attend the meetings; and he hoped he might be spared to attend them for a good many years to come. He was much obliged to the Members for placing him in the position he now

(The President.)

occupied as their President, which he certainly had never expected; and having promised to do the best he could for the Institution, he would endeavour to keep his word.

RESEARCH COMMITTEE ON MARINE-ENGINE TRIALS.

REPORT UPON TRIALS OF THREE STEAMERS, "FUSI YAMA," "COLCHESTER," "TARTAR."

By Professor ALEXANDER B. W. KENNEDY, F.R.S., *Chairman.*

The Research Committee on Marine-Engine Trials, appointed some three years ago by this Institution, had the pleasure this time last year of presenting a report on the first of their trials, which was made upon a triple-expansion engine in the s.s. "Meteor" running between Leith and London (Proceedings 1889, page 235). The report now presented is on three more trials. The first of these was upon the "Fusi Yama," which may be taken as a fair specimen of the ordinary coasting steamer, with two-cylinder compound engine, working with a boiler pressure of 60 or 70 lbs. above the atmosphere. The engine was in reasonably good order and reasonably economical; and such engines are used by hundreds throughout the mercantile marine, and often on long voyages, without special pretensions to economy. It was tested under ordinary working conditions, as has been the case also with all the others tried. The second steamer tried, the "Colchester," is one of the latest belonging to the Great Eastern Railway, and has twin-screw two-cylinder compound engines. The third vessel was the "Tartar," a fine example of the triple-expansion engines used in large cargo steamers, working with 140 or 150 lbs. boiler pressure and fitted with steam-jackets. The engines are in every way finely designed. In the particular trial here reported it will be seen that these engines were considerably underworked, but this could not be helped, owing to the steamer being light on the occasion; no more power could be got out of the engines than they could be allowed to give under the circumstances of so light a load. All three of these trials were made at sea, and they were all made as nearly as possible on the same plan, and with the same apparatus.

1. TRIAL OF THE S.S. "FUSI YAMA."

Steamer.—This steamer was tested as a good example of an ordinary trading vessel working under the usual conditions. She belongs to Messrs. Gellatly, Hankey, Sewell and Co., to whom the Committee are much indebted for giving them every facility for making the experiments. She is a vessel of 214·3 feet length between perpendiculars, 29·3 feet beam, and 20·5 feet depth. Her registered tonnage is 632 net, and her gross tonnage 994, under deck 899 tons. Her displacement on the day of the trial, when the mean draft was 18 feet $11\frac{3}{4}$ inches, was 2,175 tons.

The trial was made upon the 14th and 15th November 1888, on a run from Gravesend to Portland. The ship left Gravesend, where her compasses had been adjusted, about six o'clock on the afternoon of the 14th November, and the trial started at 8.51 p.m. on that evening. It lasted until 11.0 a.m. on the 15th. The run was continuous, with the exception of stoppages amounting in all to 12 minutes between 3.10 and 3.25 a.m. when landing the pilot off Dover. In addition to this the engines were running slow for about 13 minutes between 3.0 and 3.30 a.m. The reading of the counter was entered at each change of speed or stoppage during this time.

Engines.—The "Fusi Yama" is fitted with compound surface-condensing engines, made by Mr. Martin Samuelson of Hull in 1874. They had been thoroughly overhauled by Messrs. Rait and Gardiner, under the superintendence of Mr. Frederick Edwards, immediately before the trial, and were in thoroughly good working order. The cylinder diameters are 27·35 inches and 50·3 inches, measured from gauges. Their common stroke is 33 inches. The diameter of both piston-rods is 4·9 inches. There are no tail-rods.

The cranks are at right-angles, the low-pressure leading.

The cylinders are not jacketed. The clearances of the high and low-pressure cylinders as measured on the drawings are respectively 8·5 and 5·0 per cent. Sections of the cylinders are shown in Plates 104 and 105.

"Fusi Yama."

Each cylinder is provided with a single slide-valve worked by the ordinary link-motion gear. The throttle and stop valves, and the link-motion, were sealed up at starting. The link-motion however was opened out a little at 1·24 a.m., and remained in its new position during the rest of the run. The screw propeller is four-bladed, having a diameter of 13 feet, and a mean pitch of 16·37 feet.

Boiler.—Steam is supplied by one boiler 13 feet $3\frac{3}{4}$ inches mean diameter, 11 feet long, and containing three furnaces. The total grate area is 52 square feet, and the total heating surface 2,257 square feet, the ratio between the two being 1 to 43·4. The mean diameter of the flues is 2 feet $11\frac{1}{2}$ inches. The fire-bars are of the ordinary description; and there are 17 bars in the width of each furnace, and therefore 34 in each grate. There are 232 tubes of $3\frac{3}{4}$ inches external diameter, and 7 feet 5 inches long between plates, equivalent to a total tube surface of 1,689 square feet, which is 32·5 times the grate area. The internal diameter of the funnel is 4 feet $6\frac{1}{2}$ inches, and its total height is 43 feet 2 inches above the centre of the lowest furnace. Sections of the boiler are shown in Plate 106.

The total weight of the engines and boiler, including water in condenser, pipes, and boiler, and all mountings, is about 100 tons. The net volume of the boiler is about 1,681 cubic feet.

Duration of Trial.—The duration of the trial from start to finish was 14 hours 9 minutes. Deducting the 12 minutes of stoppage, the running time was therefore 13 hours 57 minutes, or 837 minutes.

Coal Measurement.—The same method was used for weighing the coal as was employed upon the "Meteor" trial (Proceedings 1889, page 237). About 70 lbs. of coal was weighed in each bucket, and about nine buckets were weighed on to the stoke-hold floor at one time. The trial was started with a clean floor. The time was noted at which each lot of weighed coal was put upon the fire, and no more coal was weighed out until the floor was again clear. The line of coal consumption plots out as shown in the diagram,

"Fusi Yama."

Plate 88. The fires were not cleaned during the run. The ashes were weighed after the trial was over. The coal was West Hartley Tyne coal, costing 15*s.* 9*d.* per ton. It was somewhat irregular in quality, but a sample collected at different times during the run, and afterwards well mixed and pounded, gives the following analysis, which has been made by Mr. C. J. Wilson:—

	Coal as used.	Dry Coal.
Carbon	70·85 per cent.	77·52 per cent.
Hydrogen	4·71 „ „	5·15 „ „
Moisture	8·60 „ „	0·00 „ „
Ash	5·11 „ „	5·59 „ „
Nitrogen, Sulphur, Oxygen, &c., by difference	10·73 „ „	11·74 „ „
	100·00	100·00

The calculated calorific value of this fuel as used is 12,760 thermal units per lb., which is equivalent to the evaporation of 13·21 lbs. of water from and at 212° Fahr. The equivalent carbon-value of this fuel as used is 0·878 lbs. per lb. The total coal used was 13,768 lbs. in 849 minutes. As out of the whole time of running, the engines were stopped for 12 minutes, during which period of course the fires were more or less damped, it may be taken that the actual time of firing was equivalent to about 840 minutes; but in order not to confuse matters the boiler time will be taken as equal to the engine time, that is to say, to the time during which the engines were actually running, namely 837 minutes. The total coal was therefore 16·45 lbs. per minute, or 987 lbs. per hour. The weather was fair until reaching Dover, but became very rough during the last part of the trial, which was brought to an end somewhat sooner than was intended, because of the great difficulty of obtaining further accurate measurements. Up to the actual point of ceasing observations, however, the weather did not affect their accuracy, although it rendered difficult the estimation of the water-level in the boiler at the end of the trial. The roughness of the weather at the end of the trial prevented accurate measurements being made as to the amount of clinker obtained from cleaning the fires. The actual

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amount of ash weighed off from under the grates was only 278 lbs., or about 2 per cent. of the total weight of the fuel.

Furnace Gases.—The temperature of the chimney gases was observed fifteen times during the trial, and its average value was 578° Fahr.; the highest reading being 617°, and the lowest (which was just after starting) 500°. The observations are plotted in Fig. 9, Plate 91. Two samples of furnace gases were collected and analysed; the analyses of these by weight and by volume are given in the following table:—

TABLE 3.—*Percentage Composition of Flue Gases.*

Constituent.	No. 1.		No. 2.		Mean.	
	By Volume.	By Weight.	By Volume.	By Weight.	By Volume.	By Weight.
Carbonic Acid .	6·93	10·30	8·14	12·04	7·53	11·17
Carbonic Oxide .	0·00	0·00	0·00	0·00	0·00	0·00
Oxygen . .	12·14	13·13	11·00	11·84	11·57	12·48
Nitrogen . .	80·93	76·57	80·86	76·12	80·90	76·35
	100·00	100·00	100·00	100·00	100·00	100·00

The mean chimney draft, which was measured by a U gauge-glass at the place where the furnace gases were collected, was 0·28 inch of water.

Feed-Water Measurement.—The feed-water was measured in the same way as for the "Meteor," on its way from the hot-well to the feed-pump of the engine. The tanks used for weighing it (which held about 260 lbs. each) were placed on the upper engine-room platform; their contents were carefully tested by weighing water into them, and they were at the same time ascertained to be free from any leakage. The necessary correction having been made for the

temperature of the feed, the total water used amounted to 109,800 lbs. (its mean temperature being 129·5° Fahr.), over a total time of 850 minutes. The engine was actually running during 838* minutes of this time, so that the mean consumption of water per minute (engine time) was 131·0 lbs., or 7,860 lbs. per hour. The continuous consumption of feed-water is shown in Plate 88, and the temperature is plotted in Fig. 11, Plate 91.

All the steam made by the boilers went to the main engine, steam being kept up in the donkey boiler for any other purposes that were required.

Power Measurement.—Indicator diagrams were taken at about half-hourly intervals throughout the whole of the trial, 26 sets or 104 diagrams being taken in all. A pair of Darkes' indicators with 1–30th springs, were used on the high-pressure cylinder, and a pair of Richards' indicators with 1–10th springs on the low-pressure cylinder. The following are the mean effective pressures in the two cylinders in pounds per square inch :—

Cylinder.	Top.	Bottom.	Mean.
High-pressure . .	31·06	30·41	30·74
Low-pressure . .	10·43	11·30	10·87

These pressures correspond with the following indicated horse-powers :—

High-pressure cylinder	168·2
Low-pressure cylinder	203·1
Total Indicated Horse-Power	371·3

One set of diagrams was taken during the time when the engines were slowed down (13 minutes), and the proper allowance has been made for this in the preceding averages.

The maximum indicated horse-power given by any one set of diagrams was 402·2, which occurred at 5.30 a.m., with 57·5

* The last feed-tank was emptied at 11·1 a.m., or one minute after the last reading of the counter.

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revolutions per minute, and boiler pressure of 59·0 lbs. per square inch. The minimum indicated horse-power by any one set of diagrams at full speed was 313·0 at 11.0 p.m., with 53 revolutions per minute, and boiler pressure of 49 lbs. per square inch. In Plate 90 is given the set of diagrams nearest to the mean, taken at 9.30 p.m. with 55·9 revolutions per minute and boiler pressure of 57 lbs. per square inch. From the 104 diagrams which were taken during the trial a mean diagram has been plotted for each of the two cylinders, and these are given in Fig. 10, Plate 91. The continuous variations of boiler pressure and cylinder mean effective pressures are shown in Fig. 6, Plate 89; of horse-power in Fig. 4; and of speed in Fig. 5.

Speed.—The counter read 8,507 at 8.51 p.m. when the trial commenced, and 55,033 at 11.0 a.m. when the trial ended. The total number of revolutions made by the engines was therefore 46,526 in a total running time of 837 minutes, which gives an average rate of 55·59 revolutions per minute. The maximum number of revolutions per minute for any half-hour was 57·5, and the minimum number (except when slowed down) was 53·0. The continuous increase of total revolutions from the beginning of the trial is shown in Plate 88.

Pressures, &c.—The mean barometric pressure during the trial was 30·1 inches of mercury, or 14·8 lbs. per square inch. The mean boiler pressure was 56·84 lbs. per square inch above the atmosphere, measured on the gauge in the stoke-hold. On the engine-room gauge the mean pressure was 55·2 lbs. per square inch. It will be seen from the diagram, Fig. 6, Plate 89, that the boiler pressure was fairly constant, except during about two hours near the beginning of the run, and during the time when the engines were slowed down. The pressure-gauge in the stoke-hold was read every quarter of an hour during the trial, and the other gauges were read every half-hour alternately with the counter readings, and at the same time as that at which the indicator diagrams were taken. The mean reading of the vacuum-gauge was

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25·40 inches of mercury, or 12·48 lbs. per square inch below the atmosphere. The mean initial pressure in the high-pressure cylinder (from measurement of diagrams) was 50·3 lbs. per square inch above the atmosphere; and the mean back-pressure in the low-pressure cylinder was 10·9 lbs. per square inch below the atmosphere, which corresponds to an absolute back-pressure of 3·9 lbs. per square inch in the cylinder.

Boiler Efficiencies.—The rate of combustion in the furnaces was 18·98 lbs. of coal per square foot of grate surface per hour, or 0·437 lb. per square foot of total heating surface per hour. The evaporation was at the rate of 7·96 lbs. of water per lb. of coal. As the feed entered the boiler at a temperature of 129·5° Fahr., and as the temperature corresponding to the mean steam-pressure was 304° Fahr., each lb. of steam must have taken up 1,077 thermal units; so that the equivalent evaporation from and at 212° Fahr. was 8·87 lbs. of water per lb. of coal, or about 10·10 lbs. per lb. of carbon-value in the fuel. The equivalent amount of heat utilised per lb. of coal was 8,570 thermal units, or say 67·2 per cent. of the whole calorific value of the fuel; which percentage therefore represents the actual boiler efficiency.

The total nominal calorific value of the fuel burnt per minute was 209,900 thermal units. Assuming that the two samples of furnace gases analysed gave a fair average value, it appears that the weight of dry air per lb. of coal was about 22·8 lbs. The loss of heat in raising the temperature of the furnace gases from 55° Fahr., allowing for the steam due to the combustion of the hydrogen in the fuel, works out to 2,995 thermal units, or 23·5 per cent. of the whole calorific value of the fuel. There was no loss by formation of carbonic oxide. The loss due to evaporation of the moisture in the fuel would be 0·9 per cent. These quantities add up to 91·6 per cent. of the whole heat of combustion, the balance of 8·4 per cent. including all losses by radiation. The weight of water evaporated per square foot of total heating surface was 3·48 lbs. per hour. The average rate of transmission of heat through the material of the boiler

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was 3,750 thermal units per square foot of total heating surface per hour.

Coal Consumption.—The total coal burnt, namely 987 lbs. per hour, corresponds to 2·66 lbs. per indicated horse-power per hour. This is equivalent to 2·33 lbs. of carbon-value per indicated horse-power per hour.

Engine Efficiencies.—The measurement of feed-water shows that the quantity used per indicated horse-power was 21·17 lbs. per hour. The actual heat received by the feed-water per minute was 141,100 thermal units, or 380 thermal units per indicated horse-power per minute, which is 67·2 per cent. of the whole heat of combustion. The absolute engine efficiency, or ratio of the heat turned into work to the total heat received by the feed-water, was 11·25 per cent.

Total Efficiency.—The combined efficiency of the boiler and engines, or the ratio of the heat turned into work to the total heat of combustion of the fuel, was $0{\cdot}672 \times 0{\cdot}1125$, which is equivalent to 7·6 per cent.

Steam from Indicator Diagrams.—The following are the results of measurements made upon all the indicator diagrams taken, to ascertain the proportion of steam accounted for by them. The actual weight of feed-water used per revolution was 2·36 lbs.:—

Proportion of Steam accounted for by indicator diagrams.	Lbs. per Revolution.	Percentage of Total Feed.	Percentage present in cylinder as water.
Steam present in high-pressure cylinder after cut-off, when the pressure was 45·2 lbs. per square inch above the atmosphere	Lbs. 1·96	Per cent. 83·1	Per cent. 16·9
Steam present in low-pressure cylinder near end of expansion, when the pressure was 4·8 lbs. per square inch below the atmosphere	1·67	70·8	29·2

2. TRIAL OF THE S.S. "COLCHESTER."

Steamer.—This vessel is the latest of those built for the Great Eastern Railway Co., for carrying their passenger traffic between Harwich and Antwerp. The Committee are very greatly indebted to the Great Eastern Railway Co., and especially to Mr. Holden, the locomotive superintendent of the line, and to Captain Howard, the Company's marine superintendent, for the facilities which they gave throughout for the carrying on of the trial. The "Colchester," which is driven by twin screws, is a vessel of 281 feet length, 31·feet beam, and 15·3 feet depth. Her gross registered tonnage is 1,160, while her net registered tonnage is only 517; the remainder of 643 tons representing space occupied by machinery, seamen, &c. Her draft at Harwich at the end of the trial was 13 feet 7 inches aft, and 10 feet 6 inches forward; corresponding to a displacement of 1,675 tons.

The trial was made upon the 9th November 1889, on a run from the Humber to Harwich. The ship had been lying in the Humber, where her machinery had received a thorough overhauling by the makers, Messrs. Earle's Shipbuilding and Engineering Company, Hull. Steam was got up on the morning of the 8th November, and the engines were turned round about 3 p.m. on that day. The steamer left her moorings about 3 a.m. on the 9th November, and the trial started at 5 a.m. on that morning. It lasted until 4 p.m. exactly, the boat being taken a little south of the Stour estuary in order somewhat to prolong the trial. The furthest point south was reached at 3 p.m. The engines were stopped about 7 minutes during this time to allow the pilot to leave the ship, and they were also slowed down for 5 minutes about the same time. The counter was read at each of these changes of speed, all of which occurred before 5.40 a.m.

Engines.—The "Colchester" is fitted with two compound surface-condensing engines, driving the two screw shafts. The engines are entirely separate, and are placed slightly inclining from the vertical, the space between them being taken up by a condenser which is

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common to the two. They were built by Messrs. Earle's Shipbuilding and Engineering Co. in 1888–89. The vessel had been on her station running to Antwerp and back twice every week from the end of February to the middle of September 1889, and had run a total distance of about 16,530 miles during that time; and had undergone her first overhaul at the makers, as already mentioned, during the week before the trial. The engines and boilers therefore were in thoroughly good order. The diameters of the cylinders are 30 inches and 57 inches respectively. An opportunity has not occurred to gauge them. Their common stroke is 36 inches. The diameter of all piston-rods is 6·0 inches, and of all tail-rods 4·5 inches. The cranks of each engine are at right-angles, and the high-pressure cranks lead. The cylinders are not jacketed. The clearances of the high and low-pressure cylinders as given by the owners are 9·39 and 6·23 per cent. Sections of the cylinders are shown in Plates 107 and 108.

The valve-gear is of the ordinary link-motion type. The surface-condenser contains 3,000 square feet of tube surface in 1,176 tubes, 1 inch external diameter, and 9 feet $9\frac{3}{4}$ inches long between plates. The screw propellers have cast-steel blades and boss; each is 11 feet 6 inches diameter, and 20 feet $4\frac{1}{2}$ inches pitch, with a surface of $45\frac{1}{2}$ square feet.

Boilers.—There are two iron boilers, each double-ended, 13 feet mean diameter, and 18 feet 3 inches long; each boiler having six furnaces of 3 feet 4 inches internal diameter. The total grate surface is 220 square feet; the length of each surface on bars being 5 feet 6 inches. The total heating surface is 5,820 square feet, of which 4,770 square feet is tube surface. There are 784 tubes, $3\frac{1}{2}$ inches external diameter, and 6 feet $7\frac{5}{8}$ inches long between plates. The total heating surface is therefore 26·5 times, and the tube surface 21·7 times the grate surface. The boilers have been designed to work safely with a pressure of 90 lbs. of steam, but are ordinarily worked, as during the trial, with a pressure from 5 to 10 lbs. less. There are two double funnels, one for each stoke-hold; the internal diameters of their outer and inner shells

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are respectively 6 feet 7 inches, and 5 feet 5 inches, and the total height of each funnel is 47 feet above the centre of the wing furnaces. Sections of one of the boilers are shown in Plate 109.

The total weight of the engines and boilers, including water in condenser, pipes, and boilers, and all mountings, is about 395 tons. The net volume of the boilers is about 4,980 cubic feet.

Duration of Trial.—The duration of trial from start to finish was 11 hours exactly. Deducting the 7 minutes of stoppage, the running time was therefore 10 hours 53 minutes, or 653 minutes.

Coal Measurement.—The coal was weighed in each stoke-hold by spring balances as before. From 500 to 700 lbs. of coal was put down at one time on each side of each stoke-hold. The trial was started with clean floors in each stoke-hold. The time was noted at which each lot of weighed coal was put upon the fire, and no more coal was weighed out until the floor was again clear. The line of coal consumption plots out as shown in Plate 92. The fires were not cleaned during the run. The ashes were weighed after the trial was over; but the weight of the ashes given below includes the ash formed while steam was being raised during the time the fires were banked up before the start, and during the two hours' run before the trial actually commenced. The fire-grates were fitted with Henderson's fire-bars, with the object mainly of rendering possible a somewhat larger rate of combustion, so as to get the greatest possible duty out of the boilers. The coal used in the forward stoke-hold, and during the first half of the run in the after stoke-hold, was Monk Bretton (Yorkshire) coal. For the second half of the run a mixed coal, chiefly Hucknall and Shireoaks (Nottinghamshire), was used in the after stoke-hold. Coal samples were taken from both stoke-holds frequently during the run, and were mixed together, and finally pounded, so as to obtain as representative a sample as possible for analysis. The analysis was made as before by Mr. C. J. Wilson, who gives it as follows:—

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	Coal as used.	Dry Coal.
Carbon	71·89 per cent.	75·08 per cent.
Hydrogen	5·42 „ „	5·66 „ „
Moisture	4·25 „ „	0·00 „ „
Ash	4·08 „ „	4·26 „ „
Nitrogen, Sulphur, Oxygen, &c., by difference	14·36 „ „	15·00 „ „
	100·00	100·00

The following is an analysis made by Mr. Wilson of a sample of the clinker and ash:—

Loss on ignition (=Carbon)	43·73 per cent.
Mineral matter	56·27 „ „
	100·00

The ash therefore contained about 43·7 per cent. of carbon.

The calculated calorific value of the fuel as used is 13,280 thermal units, which corresponds to the evaporation of 13·75 lbs. of water from and at 212° Fahr. The equivalent carbon-value of 1 lb. of the fuel as used is 0·913 lbs. The total coal used was as follows:—

After stoke-hold, port side	16,020 lbs.
„ „ starboard side	15,426 „
Forward „ port side	15,509 „
„ „ starboard side	15,536 „
	62,491 lbs.

This amounts to 95·7 lbs. per minute, or 5,742 lbs. per hour, taking the running time of 653 minutes. As a check upon the coal consumption it has also been worked out from a time after the stoppage, at about 5.40 a.m., to the end of the trial; and over this period it comes to 95·9 lbs. per minute, that is to say the same as before within the limits of measurement.

The weather was very fine during the whole of the trial, but a little foggy towards the end; which made the captain of the steamer

TABLE 4 (*continued on opposite page*).

COLCHESTER TRIAL.

Analyses of Funnel Gases by Volume.

	No. of Sample.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.
		Per cent.	Per cent.	Per cent.	Per cent.
FORWARD FUNNEL.	1	8·13	0·00	11·20	80·67
	3	10·55	1·84	6·59	81·02
	5	12·47	0·00	6·43	81·10
	7	7·98	0·00	11·79	80·23
	9	12·37	1·64	5·39	80·60
	11	9·89	0·00	9·72	80·39
	13	11·18	0·00	8·30	80·52
	15	10·60	0·00	9·17	80·23
	17	11·80	0·00	6·45	81·75
	19	11·27	0·00	7·67	81·06
	Mean	**10·62**	**0·35**	**8·27**	**80·76**
AFTER FUNNEL.	2	7·75	0·00	11·27	80·98
	4	8·93	0·00	10·66	80·41
	6	8·72	0·00	11·21	80·07
	8	6·18	0·00	13·46	80·36
	10	6·33	0·00	13·69	79·98
	12	3·01	0·00	17·66	79·33
	14	9·97	0·00	9·72	80·31
	16	12·08	1·15	5·90	80·87
	18	9·90	0·00	10·37	79·73
	20	5·94	0·00	14·09	79·97
	Mean	**7·88**	**0·12**	**11·80**	**80·20**
Mean of Both Funnels		**9·25**	**0·23**	**10·04**	**80·48**

(*continued from opposite page*) TABLE 4.

COLCHESTER TRIAL.

Analyses of Funnel Gases by Weight.

No. of Sample.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.	Time of Collecting.
	Per cent.	Per cent.	Per cent.	Per cent.	
1	12·02	0·00	12·05	75·93	5.20 a.m.
3	15·50	1·72	7·04	75·74	6.20 „
5	18·14	0·00	6·80	75·06	7.20 „
7	11·80	0·00	12·68	75·52	8.25 „
9	18·03	1·52	5·71	74·74	9.40 „
11	14·52	0·00	10·38	75·10	10.40 „
13	16·33	0·00	8·82	74·85	11.40 „
15	15·52	0·00	9·76	74·72	12.40 p.m.
17	17·22	0·00	6·85	75·93	2.5 „
19	16·47	0·00	8·15	75·38	3.5 „
Mean	**15·56**	**0·32**	**8·82**	**75·30**	
2	11·48	0·00	12·15	76·37	5.50 a.m.
4	13·16	0·00	11·43	75·41	6.50 „
6	12·86	0·00	12·02	75·12	7.55 „
8	9·21	0·00	14·59	76·20	9.10 „
10	9·42	0·00	14·82	75·76	10.10 „
12	4·54	0·00	19·36	76·10	11.10 „
14	14·63	0·00	10·37	75·00	12.10 p.m.
16	17·62	1·07	6·26	75·05	1.35 „
18	14·52	0·00	11·06	74·42	2.35 „
20	8·85	0·00	15·28	75·87	3.35 „
Mean	**11·63**	**0·11**	**12·73**	**75·53**	
Mean of Both Funnels	**13·59**	**0·22**	**10·78**	**75·41**	

reluctant to continue the run longer, as it was originally intended to do.

The actual amount of clinker and ash weighed off under the conditions already mentioned (page 214) was 2,890 lbs. It may be taken roughly that of this quantity 2,200 lbs., or 200 lbs. per hour, was made during the actual run, which is about 3·5 per cent. of the total quantity of coal.

Furnace Gases.—A sample of the furnace gases was collected over mercury by Mr. Wilson each hour from each funnel, there being twenty samples in all. The analyses of these samples are given in Table 4, pages 216–217. This set of analyses and the corresponding set for the "Tartar" trial are perhaps the most important and complete which have ever been made under such conditions, and merit close examination. The "mean" figures in the table (page 217) show that 3·8 per cent. by weight of the dry furnace gases is carbon: from which it follows that, allowing for the combustion of the hydrogen of the fuel, 18·5 lbs. of dry air passed through the furnace per pound of coal burnt.

The chimney temperatures were read in each funnel every quarter of an hour during the whole of the trial, from a mercury thermometer containing compressed nitrogen over the mercury. This thermometer reads up to 860° Fahr.; but in a large number of cases (about 37 per cent. of the whole) the temperature rose somewhat above the maximum reading of the thermometer. It was obvious from the motion of the mercury that the true temperature was not much above the limit of the thermometer, but of course its exact value is unknown. Assuming that the mean value of these excess readings was 20° Fahr. above the limit of the thermometer, or 880° Fahr. (which is probably true within an error of 10° either way), the mean temperature in the forward funnel was 828° Fahr., and in the after funnel 842° Fahr., the mean of both being therefore 835° Fahr. The variations in temperature of the chimney gases are shown in Fig. 22, Plate 96.

The mean chimney-draft measured by U gauges was 0·38 inch of water in the forward, and 0·34 inch in the after funnel.

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Feed-Water Measurement.—The feed-water was measured in the two tanks, of which details of construction are shown in Plate 87. These tanks have been made specially for feed measurement in a form as adaptable as possible to the conditions of various steamers; and in parts of such a size that they can be readily got down into the engine-room of a steamer, and erected and jointed there. It was found possible to put them together in an extremely confined space in the "Colchester," and again in the "Tartar" at a somewhat later date; and it is thought that the details of their construction may therefore be interesting. Each tank held about 2,200 lbs. of water at 64° Fahr., between the upper and the lower cocks. Their contents were carefully tested by weighing water into them when jointed and connected, before placing them on board the steamer. The water in each tank lasted in the "Colchester" about three minutes. The total weight of water used was 468,845 lbs., over a total running time of 654 minutes.* This amounts to 717 lbs. per minute, or 43,020 lbs. per hour, the mean temperature of the feed being 113° Fahr. The continuous consumption of feed-water is shown in Plate 92, and the variations of its temperature in Fig. 24, Plate 96. The feed-pump of one of the engines only was employed to pump throughout, the other pump not being used.

All the steam made by the boilers went to the main engines; the steam for the circulating-pump engine, the steering engine, and the dynamo engine, and any steam that was required for heating, was all taken from the donkey boiler, to which special steam connections were made for the purpose. The water-level was practically the same at the beginning and the end of the trial.

Power Measurement.—Indicator diagrams were taken every half-hour from each engine. There were thus 22 sets of diagrams, or 176 single diagrams, taken in all. The eight indicators used were all made by Messrs. T. S. M'Innes and Cairns of Glasgow, by whom six of them were kindly lent to the Committee. These indicators are very simple in construction and handy in use, and their vulcanite sheathing is attended, at sea especially, with much convenience in

* The last feed-tank was finished at 4.1 p.m. instead of 4 p.m.

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manipulation. The following are the mean effective pressures in the cylinders in pounds per square inch :—

Cylinder.	Top.	Bottom.	Mean.
Port; high-pressure	43·34	47·96	45·65
„ low-pressure	13·25	13·58	13·42
Starboard; high-pressure	38·45	45·68	42·07
„ low-pressure	11·68	13·15	12·42

These pressures correspond with the following indicated horse-powers :—

Port engine; high-pressure cylinder . . .	490·3	
„ „ low-pressure cylinder . . .	532·2	1,022·5
Starboard engine; high-pressure cylinder . .	457·9	
„ „ low-pressure cylinder . .	499·3	957·2
Total Indicated Horse-Power		1,979·7

The maximum indicated horse-power given by any one set of diagrams was 2,194·2, which occurred at 10.15 a.m., with a mean speed of 88·6 revolutions per minute, and boiler pressure of 86 lbs. per square inch. The minimum indicated horse-power by any one set of diagrams was 1,699·6, at 5.45 a.m., with a mean speed of 83·2 revolutions per minute, and boiler pressure of 73 lbs. per square inch. In Plates 94 and 95 is given the set of diagrams nearest to the mean, taken at 7.45 a.m. with 86·3 and 87·2 revolutions per minute and boiler pressure of 81·5 lbs. per square inch. From the 176 diagrams which were taken during the trial, two mean diagrams have been plotted, one for the two high-pressure and one for the two low-pressure cylinders, and these are given in Fig. 23, Plate 96. The continuous variations of boiler pressure are shown in Fig. 16, Plate 93; of cylinder mean effective pressures in Fig. 17; of horse-powers in Figs. 13 and 15; and of speed in Fig. 14.

Speed.—The counters for the two engines were entirely separate. The total number of revolutions made by the port engine was 56,136, and by the starboard engine 56,857; which correspond respectively to 86·0 and 87·1 revolutions per minute. The maximum number of revolutions per minute during any half hour was 89·9 for the port, and 91·7 for the starboard engine; and the minimum

number, except when slowed down, was 82·9 for the port, and 84·0 for the starboard engine. The continuous increase of total mean revolutions from the beginning of the trial is shown in Plate 92.

Pressures, &c.—The mean barometric pressure during the trial was 30·6 inches of mercury, or 15·0 lbs. per square inch. The mean boiler-pressure was 80·5 lbs. per square inch by the pressure-gauge in the stoke-hold, and 78·2 lbs. per square inch by the pressure-gauge in the engine-room. It will be noticed from the diagram, Fig. 16, Plate 93, that the pressure was falling both at the commencement and at the end of the trial. The mean vacuum by gauge was 25·4 inches of mercury, corresponding to 2·5 lbs. per square inch of absolute back-pressure. The mean pressure in the receiver of the starboard engine was 8·0 lbs. per square inch above the atmosphere, and in that of the port engine 8·8 lbs. per square inch above the atmosphere. The mean initial pressures in the high-pressure cylinders were 64·3 lbs. per square inch above the atmosphere in the port engine, and 59·4 lbs. in the starboard engine. The mean back-pressures in the low-pressure cylinders were respectively 4·4 and 4·5 lbs. per square inch absolute.

Boiler Efficiencies.—The mean rate of combustion in the furnaces was 26·1 lbs. of coal per square foot of grate surface per hour, or 0·987 lbs. per square foot of total heating surface per hour. The evaporation was at the rate of 7·49 lbs. of water per lb. of coal. The feed entered the boiler at a temperature of 113° Fahr., and the temperature corresponding to the mean boiler-pressure was 324° Fahr., so that each lb. of steam must have taken up 1,100 thermal units; hence the equivalent evaporation from and at 212° Fahr. was 8·53 lbs. of water per lb. of coal, or about 9·34 lbs. per lb. of carbon-value in fuel. The equivalent amount of heat utilised per lb. of coal was 8,240 thermal units, or say 62·0 per cent. of the whole calorific value of the fuel, which percentage therefore represents the actual boiler efficiency.

The total calculated calorific value of the fuel burnt per minute was 1,271,000 thermal units.

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The weight of dry air per lb. of coal, calculated from the furnace gas analyses, works out to 18·5 lbs., so that the total weight of furnace gases per pound of coal would be about 19·4 lbs. Their specific heat may be taken as 0·238, and they have been raised in temperature from say 55° Fahr., the temperature of the outer air, to 835° Fahr., the temperature of the chimney gases. This corresponds to a loss of 3,714 thermal units per lb. of coal, or 28·0 per cent. of the whole calorific value of the fuel, inclusive of raising through the same range of temperature the steam formed by the combustion of the hydrogen in the fuel. The loss due to evaporation of the moisture in the fuel works out to 0·4 per cent., and that due to imperfect combustion to 1·3 per cent. These quantities add up to 91·7 per cent. of the whole heat of combustion, leaving a balance of 8·3 per cent., which includes all losses by radiation unaccounted for. The weight of water evaporated from and at 212° Fahr. per square foot of total heating surface was 8·42 lbs. per hour.

The average rate of heat transmission through the material of the boiler was 8,130 thermal units per sq. foot of heating surface per hour.

Coal Consumption.—The total coal burnt, namely 5,742 lbs. per hour, corresponds to 2·90 lbs. per indicated horse-power per hour. This is equivalent to 2·65 lbs. of carbon-value per indicated horse-power per hour.

Engine Efficiencies.—The total indicated horse-power being 1,979·7, and the total feed-water used per hour being 43,020 lbs., the feed-water used per indicated horse-power per hour was 21·73 lbs. The actual heat received by the feed-water per minute was 788,700 thermal units, or 398·4 thermal units per indicated horse-power per minute; which is 62 per cent. of the whole heat of combustion. The absolute engine efficiency, or ratio of the heat turned into work to the heat given to the feed-water, was 10·7 per cent.

Total Efficiency.—The combined efficiency of the boilers and engines, or ratio of the heat turned into work to the total heat of combustion of the fuel, was $0·62 \times 0·107$, which is equivalent to 6·6 per cent.

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Steam from Indicator Diagrams.—The following are the results of measurements made upon the indicator diagrams taken, to ascertain the proportion of steam accounted for by them. The actual weight of feed-water used per revolution was 8·28 lbs.:—

Proportion of Steam accounted for by indicator diagrams.	Lbs. per Revolution.	Percentage of Total Feed.	Percentage present in cylinder as water.
Steam present in high-pressure cylinder, port engine, after cut-off, when the pressure was 51 lbs. per square inch above the atmosphere . . .	Lbs. 3·13	Per cent.	Per cent.
Steam present in high-pressure cylinder, starboard engine, after cut-off, when the pressure was 51 lbs. per square inch above the atmosphere . .	2·83	72·0	28·0
Steam present in low-pressure cylinder, port engine, near end of expansion, when the pressure was 7 lbs. per square inch below the atmosphere .	2·18		
Steam present in low-pressure cylinder, starboard engine, near end of expansion, when the pressure was 7 lbs. per square inch below the atmosphere.	2·18	52·7	47·3

Speed of Vessel.—The following notes from the log book of the ship may be of interest:—

	Time.	Distance in Nautical miles.
Left Hull Roads	3·15 a.m.	0
Spurn Light	4·40	24
Dudgeon ,, ...	7·45	54
Cromer ,, ...	9·5	75½
Cockle ,, ...	10·35	97
Corten ,, ...	11·15	108
Shipwash ,, . . .	1·25 p.m.	140
Sunk ,, ...	2·20	151
Long Sand Head Light . .	2·40	158½
Cork Light	4·0	173
Parkeston Quay	4·35	178½

The mean speed between Dudgeon and Cork Lights, which includes nearly the whole of the trial except that portion when the vessel was slowed down and stopped, was therefore 14·4 knots.

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The "Colchester" is a vessel built to attain a maximum of power and speed over a short journey rather than a maximum of economy. Looked at from this point of view, it may be interesting to compare the relation between power developed and size of the machinery in her case, and in those of the other steamers tested. The net volume of her boilers is about 4,980 cubic feet, or at a rate of 2·52 cubic feet per indicated horse-power. This rate in the case of the "Meteor," "Fusi Yama," and "Tartar," is respectively 2·72 and 4·53 and 4·33 cubic feet per I.H.P.

3. TRIAL OF THE S.S. "TARTAR."

Steamer.—This steam-ship is owned by Messrs. Gellatly, Hankey, Sewell and Co., and is an excellent example of a cargo-carrying steamer with modern economical engines. She was built in 1887 by Messrs. R. Dixon and Co. of Middlesbrough, and engined by Messrs. Thomas Richardson and Sons of Hartlepool with triple-expansion engines, working a single screw. She is a vessel of 332 feet length, 38 feet breadth, and 27 feet depth (moulded). Her gross registered tonnage is 2,389, and she is classed at Lloyd's 100 A 1. Her draft during the trial was 8 feet 6 inches forward, and 15 feet 6 inches aft, or 12 feet mean; and her displacement at this draft was 2,250 tons. She was practically without cargo, carrying nothing but water ballast.

The trial was made upon the 27th November 1889, on a run from the Thames to Portland. The vessel had arrived in London on the 21st November, after a voyage from Australia; and the boilers were cleaned, and the engines opened out and overhauled before the trial, while the ship was unloading in the docks. Steam was got up on the evening of the 26th November, and the vessel went out of dock about 5 a.m. on the 27th. The trial started at 8.25 a.m., as soon as the vessel was far enough down the Thames to run at full speed, and lasted until 6.30 p.m. The weather during the last part of the run was sufficiently rough to cause the engines to race a little, in consequence of the light draft of the ship. At 6.30 p.m. the weather had

"Tartar."

become sufficiently bad to make the taking of accurate observations a matter of considerable difficulty; and it was therefore decided to end the trial, rather than to run any risk of having it spoilt by inaccuracies. In consequence of snowstorms met with going down the Channel, the engines were slowed from 9.52 a.m. to 10.56 a.m., and again for 11 minutes between 12 and 1 o'clock. During these periods the speed was about 64 revolutions per minute, the full speed at other times being about 71 revolutions per minute. Diagrams were taken at the slower speeds, so that they are properly allowed for in the averages. The engines were not stopped at all during the trial; and, with the exception of the intervals named, ran under constant conditions as to position of valve-gear &c., namely with the main stop-valve and the throttle-valve fully open, and the link-motion slightly linked up.

Engines.—The "Tartar" is fitted with triple-expansion surface-condensing engines, the cylinders being placed in the order—high, low, intermediate, going from forward to aft. The cranks rotate in the sequence—high, low, intermediate. The diameters of the cylinders are 26·03 inches, 42·03 inches, and 68·95 inches, by gauges. The piston-rods are all 5·5 inches diameter. There are no tail-rods. The stroke of all three cylinders is 3 feet 6 inches. The cylinders are jacketed, and there is a separate steam-admission pipe to each jacket. The clearances of the cylinders are given by the makers as 14·51, and 9·25, and 5·10 per cent. Sections of the three cylinders are shown in Plates 110 to 112.

The valve-gear is Wyllie's elliptical gear, with an independent adjustment for the cut-off. The surface condenser contains 2,250 square feet of tube surface, in 876 tubes of $\frac{3}{4}$ inch external diameter and of 13 feet $0\frac{7}{8}$ inch length between tube-plates. The screw propeller has four blades, and is 16 feet 6 inches diameter, with a pitch of 18 feet.

Boilers.—Steam is supplied by two double-ended steel boilers with Fox's corrugated flues, designed to work at a pressure of 150 lbs. per square inch. The boilers are 13 feet in mean diameter, and 14 feet

"Tartar."

9 inches long, each with two furnaces at each end, there being eight furnaces in all. The total grate area is 161 square feet, each grate being 5 feet 6 inches in length, and 3 feet 8 inches broad. The total heating surface is 5,226 square feet, of which 4,366 square feet is tube surface. The total heating surface is therefore 32·5 times, and the tube surface 27·1 times the grate area. There are 992 tubes, 3 inches diameter outside, and 5 feet $7\frac{1}{4}$ inches long between plates. The internal diameter of the funnel is 7 feet, and its total height 57 feet above the centre of the furnaces. Sections of one of the boilers are shown in Plate 113.

The total weight of the engines and boilers, including water in condenser, pipes, and boilers, and all mountings, is about 291 tons. The net volume of the boilers is about 4,710 cubic feet.

Duration of Trial.—The duration of the trial from start to finish was 10 hours 5 minutes, or 605 minutes.

Coal Measurement.—The coal was weighed as in the other cases, from 500 to 600 lbs. at a time being put down on each side of each stoke-hold. The trial was started with clean floors, and the time of first stoking from each weighed lot of coal was noted, as well as the time when the whole of the weighed coal was finished. The line of coal consumption plots out as shown in Plate 97. The fires were not cleaned during the run. The ashes were weighed after the trial was over, the ash-pits having been cleaned a little time after it commenced. The coal used throughout was Welsh from Penrikyber (Glamorganshire). Coal samples were taken from both stoke-holds frequently during the run; and the final analysis, after a thorough mixture of all these samples, is as follows:—

	Coal as used.	Dry Coal.
Carbon	87·98 per cent.	88·93 per cent.
Hydrogen	4·22 „ „	4·26 „ „
Moisture	1·07 „ „	0·00 „ „
Ash	3·42 „ „	3·46 „ „
Nitrogen, Sulphur, Oxygen, &c., by difference	3·31 „ „	3·35 „ „
	100·00	100·00

"Tartar."

A sample of the ash was also collected, and has been analysed by Mr. Wilson as follows:—

Loss on ignition (=Carbon) . .	65·53 per cent.
Mineral matter	34·47 „ „
	100·00

The calculated calorific value of the fuel is 14,995 thermal units, which corresponds to the evaporation of 15·52 lbs. of water from and at 212° Fahr., and to an equivalent carbon-value of 1·031 lbs. per lb. The total coal used was as follows:—

After stoke-hold,	port side . . .	5,322 lbs.
„ „	starboard side . .	5,052 lbs.
Forward „	port side . . .	4,701 lbs.
„ „	starboard side . .	4,162 lbs.
		19,237 lbs.

This amounts to 31·8 lbs. per minute, or 1,908 lbs. per hour. As a check upon this consumption, and in order to see how far it might be affected by any irregularities in measurement at the end of the trial, the consumption has also been worked out over a time (in average 560 minutes), at the beginning and end of which the condition of the stoke-hold floors, and of the fires, was identical, and for this interval the coal consumption works out to 32·08 lbs. per minute. It has been thought wise to assume therefore that the actual coal consumption was 32·0 lbs. per minute, or 1,920 lbs. per hour; the small difference between this and the foregoing figures was probably caused by the increasing difficulty of measurement at the very end of the trial. The total amount of ash taken from the two stoke-holds at the end of the trial was 291 lbs., but the ash-pits were not cleaned out until some little time after the trial commenced, so that this weight corresponds to a period of only 6 hours 53 minutes. The ash was therefore equivalent to 0·70 lbs. per minute, or 42 lbs. per hour; which is 2·2 per cent. of the total weight of the fuel put on the bars.

TABLE 5 (*continued on opposite page*).

TARTAR TRIAL.

Analyses of Funnel Gases by Volume.

No. of Sample.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.	Time of Collecting.
	Per cent.	Per cent.	Per cent.	Per cent.	
1	7·28	0·00	12·45	80·27	8.30 a.m.
2	7·61	0·00	11·88	80·51	9.0 „
3	8·22	0·00	11·38	80·40	9.30 „
4	6·97	0·00	13·20	79·83	10.0 „
5	5·91	0·00	14·32	79·77	10.30 „
6	6·24	0·00	13·38	80·38	11.0 „
7	6·94	0·00	13·10	79·96	11.30 „
8	6·44	0·00	13·80	79·76	12.0 noon
9	7·70	0·00	12·10	80·20	12.30 p.m.
10	6·21	0·00	13·57	80·22	1.0 „
11	8·24	0·00	12·00	79·76	1.30 „
12	5·62	0·00	14·40	79·98	2.0 „
13	6·29	0·00	13·15	80·56	2.30 „
14	6·79	0·00	12·78	80·43	3.0 „
15	6·80	0·00	13·30	79·90	3.30 „
16	6·54	0·00	12·71	80·75	4.0 „
17	6·95	0·00	13·10	79·95	4.30 „
18	6·03	0·00	13·08	80·89	5.0 „
19	6·67	0·00	13·17	80·16	5.30 „
20	6·61	0·00	13·52	79·87	6.0 „
21	5·00	0·00	15·27	79·73	6.30 „
Mean	**6·72**	**0·00**	13·12	**80·16**	

(*continued from opposite page*) TABLE 5.

TARTAR TRIAL.

Analyses of Funnel Gases by Weight.

No. of Sample.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.	Mean Funnel Temperature.
	Per cent.	Per cent.	Per cent.	Per cent.	Fahr.
1	10·80	0·00	13·43	75·77	500°
2	11·28	0·00	12·80	75·92	512°
3	12·15	0·00	12·23	75·62	503°
4	10·34	0·00	14·25	75·41	420°
5	8·81	0·00	15·52	75·67	447°
6	9·30	0·00	14·50	76·20	478°
7	10·30	0·00	14·15	75·55	511°
8	9·58	0·00	14·93	75·49	486°
9	11·40	0·00	13·03	75·57	488°
10	9·25	0·00	14·70	76·05	514°
11	12·17	0·00	12·89	74·94	504°
12	8·39	0·00	15·63	75·98	480°
13	9·37	0·00	14·25	76·38	474°
14	10·09	0·00	13·82	76·09	496°
15	10·10	0·00	14·37	75·53	464°
16	9·74	0·00	13·76	76·50	471°
17	10·32	0·00	14·14	75·54	478°
18	9·00	0·00	14·19	76·81	458°
19	9·92	0·00	14·24	75·84	440°
20	9·83	0·00	14·61	75·56	436°
21	7·48	0·00	16·61	75·91	456°
Mean	9·98	0·00	14·19	75·83	477°

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Furnace Gases.—A very complete series of furnace-gas samples was obtained, a sample being collected over mercury by Mr. Wilson every half-hour. The analyses of these samples are given in Table 5, pages 228–229.

The chimney temperatures were read every quarter of an hour throughout the trial from a mercury thermometer as before. The average reading was 477° Fahr. It remained very fairly constant during the whole trial. The variations of temperature are shown in Plate 97, and the mean temperatures for each half-hour are given in Table 5, page 229.

The chimney draft was read on a U gauge at the same time that the temperature was taken, and varied from $\frac{3}{16}$ inch to $\frac{1}{4}$ inch of water.

Feed-Water Measurement.—The feed-water was measured in the same tanks used for the "Colchester," and already described (page 219, and Plate 87). Each tank lasted in this case from five to six minutes. The total amount of water used was 217,430 lbs., over a total time of 605 minutes. This amounts to 359·4 lbs. per minute, or 21,564 lbs. per hour; but reasons are given later on (page 233) for supposing that a considerable percentage of this quantity was not actually turned into steam. The continuous supply of feed-water and the variations of its temperature are shown in Plate 97. At first pumping was carried out by one of the feed-pumps of the engine; but for the last four hours a donkey-pump was used, as it was found to give much less trouble, and to be much more conveniently under control. The steam for this donkey-pump was supplied from the main boilers.

The steam made by the boilers all went to the main engines, steam being kept up in the donkey boiler for all auxiliary engines; and the pipes and connections were all carefully examined, in order to see that no unintentional communications existed. The water-level in the boilers averaged $1\frac{1}{4}$ inch lower at the finish than at the start of the trial. This corresponds to a total of 1,874 lbs. of water, or about 0·86 per cent. of the whole feed; this amount has been added to the quantities given above. It may be interesting to notice

that an error of half an inch in reading the level in one boiler in a case like this would make a difference of about 375 lbs., or less than 0·2 per cent. of the water used.

Power Measurement.—Indicator diagrams were taken every half-hour from each end of each cylinder as before. There were thus 21 complete sets of diagrams, or 126 single diagrams, taken in all. The indicators used were those lent by Messrs. M'Innes and Cairns, which had been used also for the "Colchester." The following are the mean effective pressures in the cylinders in pounds per square inch :—

Cylinder.	Top.	Bottom.	Mean.
High-pressure .	35·74	38·04	36·89
Intermediate . .	19·92	20·23	20·07
Low-pressure . .	7·19	7·18	7·18

These pressures correspond with the following indicated horse-powers :—

High-pressure cylinder	283·7
Intermediate cylinder	408·5
Low-pressure cylinder	395·2
Total Indicated Horse-Power . . .	1,087·4

The maximum indicated horse-power given by any one set of diagrams was 1,296·7, which occurred at 8.45 a.m., with 73·2 revolutions per minute, and boiler pressure of 146 lbs. per square inch. The minimum indicated horse-power by any one set of diagrams was 719·3, at 10.10 a.m., with 61·4 revolutions per minute, and boiler pressure of 135 lbs. per square inch. In Plate 99 is given the set of diagrams nearest to the mean, taken at 11.15 a.m. with 66 revolutions per minute and boiler pressure of 141·4 lbs. per square inch. From the 126 diagrams which were taken during the trial a mean diagram has been plotted for each of the three cylinders, and these are given in Plate 100. The continuous variations of boiler pressure are shown in Fig. 27, Plate 98; of cylinder mean effective pressures in Fig. 29; of horse-power in Fig. 26; and of speed in Fig. 28.

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Speed.—The counter was read every quarter of an hour. The total number of revolutions made was 42,350 in 605 minutes, or exactly 70 revolutions per minute. The maximum number of revolutions per minute for any quarter of an hour at full speed was 73·8; and the minimum, 70·3 revolutions per minute; while the average speed during the time that the engine was slowed down was 63·7 revolutions per minute. The continuous increase of total revolutions from the beginning of the trial is shown in Plate 97.

Steam-Jackets.—As has been already mentioned, each jacket received steam through a separate valve. The connections from the jacket-drains to the hot-well were broken, and all three jackets were made to drain into a small tank placed at the back of the engine; and the rate at which the jacket-water was collected in this tank was measured fourteen times during the trial, on most occasions for a quarter of an hour continuously. The water collected in this way amounted in all to 2,476 lbs. in 175 minutes, or 14·15 lbs. per minute, which is 3·94 per cent. of the total feed. This quantity is of course included in the total feed measured through the tanks. It was not possible to jacket the high-pressure cylinder with steam of full boiler-pressure; and under these circumstances it did not appear advisable to allow any steam to pass into that jacket, which was accordingly shut off. The quantity of water given is therefore from the intermediate and low-pressure cylinder jackets only.

Pressures, &c.—The mean barometric pressure during the trial was 29·6 inches of mercury, or 14·6 lbs. per square inch. The mean boiler pressure was 143·6 lbs. per square inch by the pressure-gauge in the stoke-hold, and 140·4 by that at the engine. The pressures in the high-pressure, intermediate, and low-pressure valve-chests, were respectively 131·4 and 46·1 and 3·8 lbs. per square inch above the atmosphere. The pressures in the steam-jackets of the intermediate and low-pressure cylinders were 52·5 and 14·0 lbs. per square inch respectively. The cock admitting steam into the high-pressure jacket, although nominally shut, allowed enough steam to leak through to enable the gauge to show pressures varying from 0

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to over 50 lbs. per square inch. The actual amount of water coming from the high-pressure jacket-drain however was too small to affect appreciably the quantities given in the preceding paragraph. The mean vacuum was 26·2 inches of mercury by gauge, which corresponds to a mean absolute back-pressure in the condenser of 1·7 lbs. per square inch. The mean initial pressure in the high-pressure cylinder was 121·4 lbs. per square inch above the atmosphere; and the mean back-pressure in the low-pressure cylinder was 10·5 lbs. per square inch below the atmosphere, which corresponds to an absolute back-pressure of 4·1 lbs. per square inch in the cylinder.

Boiler Efficiencies.—The mean rate of combustion in the furnaces was 11·93 lbs. of coal per square foot of grate surface per hour, or 0·367 lb. per square foot of total heating surface per hour. The total amount of feed-water pumped into the boilers was at the rate of 11·23 lbs. per lb. of coal. As the feed entered the boiler at an average temperature of 101° Fahr., and the temperature corresponding to the mean boiler-pressure was 362° Fahr., each lb. of steam would have taken up 1,123 thermal units; and the equivalent evaporation from and at 212° Fahr., had the whole of the feed-water been turned into steam, would therefore have reached the very high figure of 13·06 lbs. of water per lb. of coal. The equivalent amount of heat utilised per lb. of coal would be 12,610 thermal units, or say 84·1 per cent. of the whole calorific value of the fuel. Such a figure, although unusually high, is of course not in the nature of things impossible; but if it really represented the evaporation in this case, it would follow (as will be seen from the figures below) that the unusual economy of the boilers was accompanied by an unusual want of economy in the engines. Fortunately the measurements made were sufficiently complete to enable it to be stated positively that (from whatever cause) the whole of the water pumped into the boilers was *not* turned into steam. The observations on which this statement is based are summarised in the next paragraph.

The very complete and uniform series of samples of chimney gases, of which the analyses have been given in Table 5, pages 228–229, enable the calculations connected with them to be made with

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considerable exactness and certainty. The weight of dry air per lb. of coal calculated from these analyses works out to 31·6 lbs., so that the total weight of furnace gases per lb. of coal would be about 32·6 lbs. The gases have been raised in temperature from the temperature of the outer air, say about 55° Fahr., to 477° Fahr., the mean chimney-temperature. Taking the mean specific heat of the gases as 0·238, this corresponds to a loss of 3,307 thermal units per lb. of coal, or 22·1 per cent. of the whole calorific value of the fuel, inclusive of raising through the same range of temperature the steam formed by the combustion of the hydrogen in the fuel. The loss due to evaporation of the moisture in the fuel is so small as to be negligible, and in no one of the twenty-one analyses was any carbonic oxide found to be present in the chimney gases. The loss by radiation was no doubt considerably less than in the "Colchester," the stoke-holds being very much cooler; but taking it as low as 8 per cent., and adding to it the 22 per cent. carried away by the chimney gases, it seems certain that the maximum boiler efficiency which can have been reached cannot have exceeded 70 per cent. This would correspond to an evaporation of 10·8 lbs. of water from and at 212° Fahr. per lb. of coal, which is about 83 per cent. of the apparent evaporation mentioned above. It is moreover to be noted that on the original log sheets memoranda were made in four or five different places at different times by different assistants who were taking indicator diagrams, that they were unusually troubled by the amount of water which came through the indicator cocks of the intermediate cylinder.

Coal Consumption.—The total coal burnt, namely 1,920 lbs. per hour, corresponds to 1·77 lbs. per I.H.P. per hour. This is equivalent to 1·82 lbs. of carbon-value per I.H.P. per hour.

Engine Efficiencies.—Although the total quantity of water pumped into the boilers per indicated horse-power per hour amounted to $\frac{21,564}{1,087·4}$, or at the rate of 19·83 lbs. per I.H.P. per hour, the quantity of *steam* consumed could not have exceeded 16·5 lbs. per I.H.P. per hour, as the figures in the foregoing paragraph show. The difference must be attributed to priming.

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Total Efficiency.—The combined efficiency of the boiler and engines, or ratio of the heat turned into work to the total heat of combustion, was 9·7 per cent.

Steam from Indicator Diagrams.—The following are the results of measurements made upon the indicator diagrams taken, to ascertain the proportion of steam accounted for by them. The actual weight of feed-water used per revolution was 5·13 lbs.:—

Proportion of Steam accounted for by indicator diagrams.	Lbs. per Revolution.	Percentage of Total Feed.	Percentage in Jackets or present in cylinder as water.
Steam present in high-pressure cylinder after cut-off, when the pressure was 115·4 lbs. per square inch above the atmosphere	Lbs. 2·32	Per cent. 45·2	Per cent. [54·8
Steam present in intermediate cylinder, when the pressure was 33·4 lbs. per square inch above the atmosphere .	2·52	49·1	50·9
Steam present in intermediate cylinder when the pressure was 9·4 lbs. per square inch above the atmosphere .	2·99	58·2	41·8
Steam present in low-pressure cylinder near end of expansion, when the pressure was 7·1 lbs. per square inch below the atmosphere . . .	3·10	60·3	39·7

Speed of Vessel.—The following notes from the log book of the ship may be of interest:—

	Time.
Left London Docks . . .	5.0 a.m.
Gravesend	7.20
Nore	8.35
Girdler Light Ship . . .	9.30
Dover	12.40 p.m.
Dungeness	2.20
Royal S. Light Vessel . . .	4.20
Beachy Head	5.0
Owers	8.0
St. Catherine	11.30
Portland	5.0 a.m.

The Research Committee on Marine-Engine Trials, in presenting to the Members of the Institution this second Report upon their work, desire it to be understood that they do not look upon their duties as yet ended. They are glad to be able to think however that they have already done enough to show that engine trials can be conducted on board ship on as complete a scale and in as scientific a method as on land, although perhaps with greater difficulty and discomfort to the observers; and that this can be done without any undue interference with the normal working of the ship or engines.

The Committee wish also to say that they hope, when their work is completed, to present a comparative summary of all their experiments, in the discussion on which many points as to the influence of design on economy can be better dealt with than at present. Their future work may be much helped however by suggestions made at this stage as to improvements in the methods or in the instruments used, or as to the best means of ensuring the accuracy, or measuring the errors, of gauges, indicators, &c. They would also point out that there still does not exist any satisfactory means for measuring the *effective* horse-power of a marine engine in its actual work, that is, the power actually expended in pushing the ship forward, as represented by the thrust of the propeller and the speed of the ship; nor for measuring the quantity of the condensing water, a knowledge of which is necessary to enable a "heat balance" for the engines to be made.

There is added to this report Table 6, pages 237–240, showing the comparative results obtained in the four trials thus far made by the Committee; and also two appendices, the first (page 241) showing the instructions given for taking indicator diagrams, and the second (page 242) giving a list of the Members of this Institution and others who have taken part in the trials.

TABLE 6 (*continued to page* 240). *Comparative Results of the Trials of Four Steamers,* "METEOR," "FUSI YAMA," "COLCHESTER," "TARTAR."

			Meteor.	Fusi Yama.	Colchester.	Tartar.
1	Name of Vessel					
2	Date of Trial		24 June 1888	14 & 15 Nov. 1888	9 Nov. 1889	27 Nov. 1889
3	Duration of Trial	hours	17·15	13·95	10·88	10·08
4	Type of Engines		Triple	Compound	Twin Compound	Triple
5	Cylinder diameter, high-pressure	inches	J 29·37	N 27·35	N (two) 30	N 26·03
6	„ „ intermediate	inches	J 44·03	—	—	J 42·03
7	„ „ low-pressure	inches	J 70·12	N 50·3	N (two) 57	J 68·95
8	Stroke, length	inches	47·94	33	36	42
9	Boilers, number of main boilers		2	1	2	2
10	„ single-ended or double-ended		double	single	double	double
11	Furnaces, total number		12	3	12	8
12	Heating surface, total	square feet	6,648	2,257	5,820	5,226
13	„ „ tubes	square feet	5,760	1,689	4,770	4,366
14	Grate area	square feet	208	52	220	161
15	Total heating surface to grate area	ratio	32·0	43·4	26·5	32·5
16	Tube surface to grate area	ratio	27·7	32·5	21·7	27·1
17	Grate area to flue area through tubes	ratio		4·0	5·5	4·5
18	„ „ to area through funnel	ratio	5·0	3·2	4·8	4·2

J = Jacketed. N = Not jacketed.

TABLE 6 (*continued from preceding page*). *Comparative Results of the Trials of Four Steamers,* "METEOR," "FUSI YAMA," "COLCHESTER," "TARTAR."

	Name of Vessel		Meteor.	Fusi Yama.	Colchester.	Tartar.
19	Mean boiler-pressure above atmosphere	lbs. per sq. inch	145·2	56·84	80·5	143·6
20	„ admission „ high-pressure cyl. above atm. ..	lbs. per sq. inch	134·4	50·3	{ 64·3 / 59·4 }	121·4
21	„ effective „ high-pressure cylinder	lbs. per sq. inch	58·46	30·74	{ 45·65 / 42·07 }	36·89
22	„ „ „ intermediate „	lbs. per sq. inch	19·50	—	—	20·07
23	„ „ „ low-pressure „	lbs. per sq. inch	12·38	10·87	{ 13·42 / 12·42 }	7·18
24	„ „ „ total referred to low-p. cyl. ..	lbs. per sq. inch	29·9	19·9	24·8	19·8
25	„ exhaust „ low-pressure cyl. below atm. ..	lbs. per sq. inch	11·6	10·9	{ 10·6 / 10·5 }	10·5
26	„ vacuum in condenser below atmosphere ..	lbs. per sq. inch	12·17	12·48	12·49	12·9
27	Revolutions per minute, mean	revs.	71·78	55·59	{ 86·0 / 87·1 }	70·0
28	Piston constant, high-pressure cylinder	H.P.	11·31	5·36	{ 10·71 / 10·84 }	7·73
29	„ „ intermediate „	H.P.	26·00	—	—	20·42
30	„ „ low-pressure „	H.P.	66·65	18·32	{ 39·55 / 40·06 }	55·27
31	Indicated horse-power, high-pressure cylinder	I.H.P.	662	168·2	{ 490·3 / 457·9 }	283·7
32	„ „ intermediate „	I.H.P.	507	—	—	408·5
33	„ „ low-pressure „	I.H.P.	825	203·1	{ 532·2 / 499·3 }	395·2
34	„ „ mean total	I.H.P.	1,994	371·3	{ 1022·5 / 957·2 }	1,087·4

TABLE 6 (*continued from preceding page*). *Comparative Results of the Trials of Four Steamers,* "METEOR," "FUSI YAMA," "COLCHESTER," "TARTAR."

	Name of Vessel	Meteor.	Fusi Yama.	Colchester.	Tartar.
35	Coal burnt per minute .. lbs.	66·75	16·45	95·7	32·0
36	„ „ per hour .. lbs.	4,005	987	5,742	1,920
37	„ „ per square foot of grate area per hour .. lbs.	19·25	18·98	26·1	11·93
38	„ „ per square foot of total heating surface per hour .. lbs.	0·602	0·437	0·987	0·367
39	„ „ per indicated horse-power per hour .. lbs.	2·01	2·66	2·90	1·77
40	Carbon-value of 1 lb. of coal as used .. lbs.	0·878	0·878	0·913	1·031
41	„ „ equivalent per I.H.P. per hour .. lbs.	1·76	2·33	2·65	1·82
42	Feed-water per minute .. lbs.	497·7	131	717	359·4
43	„ „ per hour .. lbs.	29,860	7,860	43,020	21,564
44	„ „ per square foot of total heating surface per hour .. lbs.	4·49	3·48	7·39	4·13
45	„ „ per lb. of coal .. lbs.	7·46	7·96	7·49	[11·23]
46	„ „ per lb. of coal from and at 212° F. .. lbs.	8·21	8·87	8·53	[13·06]
47	„ „ per lb. of carbon-value from and at 212° F. .. lbs.	9·62	10·10	9·34	[12·67]
48	„ „ per indicated horse-power per hour .. lbs.	14·98	21·17	21·73	[19·83]
49	Calorific value of 1 lb. of coal as used .. thermal units	12,770	12,760	13,280	14,995
50	Percentage of line 49 taken up by feed-water .. per cent.	62·0	67·2	62·0	—
51	„ „ „ „ carried away by furnace gases .. per cent.	21·9	23·5	28·0	22·1
52	„ „ „ „ lost by imperfect combustion .. per cent.	3·6	0·0	1·3	0·0
53	„ „ „ „ expended in evaporating moisture in coal, per cent.	1·2	0·9	0·4	0·0
54	„ „ „ „ unaccounted for .. per cent.	11·3	8·4	8·3	—

TABLE 6 (*concluded from page* 237). *Comparative Results of the Trials of Four Steamers,* "METEOR," "FUSI YAMA," "COLCHESTER," "TARTAR."

	Name of Vessel	Meteor.	Fusi Yama.	Colchester.	Tartar.
55	Heat taken up by feed-water per minute .. .. thermal units	528,600	141,100	788,700	[403,600]
56	,, turned into work per minute .. .. .. thermal units	85,240	15,870	84,630	46,490
57	,, taken up by feed-water per I.H.P. per minute thermal units	265·6	380·0	398·4	[371·2]
58	Efficiency of boiler (line 50) .. .. per cent.	62·0	67·2	62·0	—
59	,, of engine (line 56 ÷ line 55) .. .. .. per cent.	16·1	11·2	10·7	[11·5]
60	,, of engine and boiler combined (line 58 × line 59) per cent.	10·0	7·6	6·6	9·7
61	Mean velocity of steam thro' water-surface in boilers per min. feet	..	6·28	8·60	3·43
62	Space occupied by boilers per I.H.P. .. .. cubic feet	2·72	4·53	2·52	4·33
63	Weight of engines, boilers, &c., with water, per I.H.P. .. .. tons	0·20	0·27	0·20	0·27
64	Clearance volume, high-pressure cylinder .. .. .. per cent.	12·4	8·5	{9·39 / 9·39}	14·51
65	,, ,, intermediate ,, ... per cent.	9·3	—	—	9·25
66	,, ,, low-pressure ,, ... per cent.	8·02	5·0	{6·23 / 6·23}	5·10
67	Clearance surface, high-pressure cylinder .. .. .. square feet	..	17·3	{22·6 / 22·6}	25·4
68	,, ,, intermediate ,, ... square feet	..	—	—	40·1
69	,, ,, low-pressure ,, ... square feet	..	42·5	{56·9 / 56·9}	79·6
70	Speed of vessel, mean during trial .. .. knots	14·6	..	14·4	..

Appendix 1.

Instructions given for taking Indicator Diagrams.

See that indicators have proper length of stroke and are not on stops.

Blow through before taking every diagram.

Mark number of diagram in top right-hand corner.

Let H.P. top diagrams begin with No. 1, H.P. bottom with 101; I.P. top with 201, I.P. bottom with 301; L.P. top with 401, and L.P. bottom with 501.

Let top and bottom diagrams of each cylinder be taken as nearly as possible together, and the whole set as quickly as possible.

After having taken a set of diagrams and entered time in log &c., put new papers on at once for the next set.

Draw atmospheric line by hand with full stroke.

First watch to get indicators ready before starting, and note on log sheet numbers of indicators and marks and scales of springs.

Second watch to verify these numbers, and after taking last diagrams on the watch interchange top and bottom indicators of each cylinder.

Third watch to verify the changed numbers.

Fourth watch, after taking last set of diagrams, to take indicators off and put them in boxes.

Examine every set of diagrams before putting away, to detect anomalies or errors. Compare top and bottom diagrams of each cylinder for length, pressure and general appearance. If any difference is noticed, or anything suspicious about diagrams, report at once to engineer in charge of watch.

Keep the indicator boxes shut, and the papers in them.

APPENDIX 2.

Staffs of Observers.

* Members of the Institution are marked with an asterisk.

In the "Fusi Yama" trial one watch was taken by Mr. R. H. Willis, with Messrs. L. A. Legros* and J. R. Sharman; and the other by Professor Kennedy,* with Messrs. P. G. Evans and A. P. Head.* Mr. Frederick Edwards,* as superintendent engineer for the owners, took general charge of the working of the engines throughout.

In the "Colchester" trial Mr. Frederick Edwards* took one watch, with Messrs. A. G. Ashcroft, R. H. Willis, P. G. Evans, J. R. Sharman, L. S. Robinson, W. E. Burgess, A. P. Head,* and J. T. Ewen; while Professor Kennedy* took the other watch, with Mr. E. L. Morris,* Professor T. H. Beare, and Messrs. H. R. J. Burstall,* E. C. de Segundo, L. A. Legros,* D. White, and W. A. Cloud. Mr. C. J. Wilson collected the gas samples personally during the whole of the trial.

In the "Tartar" experiments Mr. Frederick Edwards* took one watch, with Messrs. A. G. Ashcroft, C. L. Simpson,* L. A. Legros,* J. R. Sharman, A. P. Head,* Hubert Cochrane, and J. T. Ewen; and Professor Kennedy* took the other watch, with Messrs. R. H. Willis, R. Rogers, D. Capper, E. C. de Segundo, P. G. Evans, W. E. Burgess, and W. A. Cloud. Mr. Wilson again collected the whole series of gas samples personally; and Mr. Bryan Donkin, Jun.,* attended to other duties on deck.

The Captains and Chief Engineers of the three vessels—Captain J. Caine and Mr. W. Towers of the "Fusi Yama," Captain W. Nickerson and Mr. I. Cartlidge of the "Colchester," and Captain D. S. Bailey and Mr. W. Brown of the "Tartar"—gave every assistance to the staff in carrying out the observations, and by their valuable co-operation contributed materially to the success of the trials; and mention should not be omitted of the kind help received from Captain Howard and Mr. Derry, of the Great Eastern Railway, upon the "Colchester" trial.

Discussion.

The President was sure the Members would wish at once to pass a vote of thanks to the owners who had so kindly lent their ships for the trials now reported, and to the Captains and Chief Engineers of the ships who had rendered so much assistance for carrying out the trials. He therefore moved that the thanks of the Institution be given to Messrs. Gellatly Hankey Sewell and Co., the owners of the "Fusi Yama" and the "Tartar," and to the Great Eastern Railway Co., the owners of the "Colchester"; and also to the Captains of the three vessels, and the Chief Engineers and their staffs. He also proposed a vote of thanks to Mr. Wilson, who had so obligingly collected and analysed the samples of the furnace gases and made the analyses of the coal and ash; that was a work which must have been attended with a great amount of labour, and, so far as could be made out from the trials themselves, it had been very well and very carefully done.

The votes of thanks were passed with applause.

Mr. William Laird, Member of Council, though hardly prepared to enter upon any criticism of the report or of the many facts given in it, could at any rate join in complimenting Professor Kennedy upon the skilful way in which he had organized the trials, and upon the efficient and zealous manner in which they had been carried out by the staffs of observers. There was a great amount of information contained in the present report, which when properly studied and developed would be most useful in a practical way to those who had to compare the working of different engines for the purpose of still further economizing their performance. In his opinion the records of such trials were of great value; and if they could be extended to embrace a few more examples of recently constructed marine engines, the data would be of still greater value for comparison and guidance in the efforts yet further to promote economy in combination with efficiency. It was quite true that the

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first trials or trial trips of marine engines, and the performance of ships of all kinds, had for many years past been made the subject of most careful observation by leading engineers and shipbuilders; and the regulations drawn up by the Admiralty for trials of ships of war were very complete, and in many instances had formed a sort of guide for the trials of machinery for commercial purposes. It seemed to him however that the scheme drawn up by Professor Kennedy and his Committee, and carried out in the trials now reported, took in more than the conditions usually observed, and gave special attention to the boiler and to the conditions under which the coal was burnt and the heat utilized; and the observations thus made he thought might have special value, now that assisted draught in stoke-holds by the aid of fans was not unusual. Speaking generally, it was important that any data put forward under the auspices of this Institution should be correct and reliable; and in the hands of Professor Kennedy and his colleagues he felt sure this investigation was being most carefully conducted, and would prove of great help for purposes of comparison and advancement.

Mr. EDWARD H. CARBUTT, Past-President, gladly joined in thanking Professor Kennedy and all the gentlemen who had helped him to give the reliable data which had been placed before the Members. There was one question that he should like to raise in regard to the steam for the circulating-pump engine (page 219), which was stated to be supplied from the donkey boiler. Surely the work done by the circulating pump was part of the work of the engine; and the steam consumed by the circulating-pump engine ought therefore to be added to the steam consumed by the main engines. To that extent he thought the data from the three different types of engines could not be fully compared. Although himself an old marine man, having been some years at Messrs. Palmer's, he certainly should not like to enter into the discussion of the present report until he had had an opportunity of going through the figures much more thoroughly, and particularly those given in the comparative Table 6, which appeared to him to contain the gist of the whole research, and had been so well put together that it was easy to find the information

desired on any point. The Committee had rendered an important service, not only to the Institution, but to the whole country; and he thought the result might already be found in the pockets of steamship owners, of whom one of the largest had lately stated that, although during the last five or six years his coal had gone up five shillings a ton, yet his working expenses had not increased. This clearly pointed to the fact that marine engines had been able to do more work per lb. of coal; and to that extent the improvement was for the benefit of the trade of the country. It was well known that this country did three-fourths of the carrying trade of the world; and it was therefore a great gain that, although coal had gone up to the extent of five shillings a ton, the working expenses had not increased. The trials now made he was confident would help still further towards economising in marine-engine work.

Mr. J. H. HALLETT considered the report now presented was a most important one in itself, and he was also glad to infer from page 236 that still further experiments were contemplated, which he trusted would throw yet more light upon the subject of marine-engine efficiency. Such trials had until recently been very much neglected, principally he thought owing to the hurry with which ordinary cargo steamers were worked, giving little or no time for experiments or investigations of any sort. Now however that there was a better educated class of sea-going engineers, he trusted the difficulties in the way of further research might be got over. What struck him most particularly in the present report was the smoke analysis, which revealed so remarkable a difference in the quantity of air supplied in the three steamers, amounting to 22·8 and 18·5 and 31·6 lbs. of air per lb. of coal in the "Fusi Yama," "Colchester," and "Tartar" respectively. This great difference seemed surprising, as the boilers were all of the ordinary modern kind. He quite agreed with Mr. Carbutt (page 244) that some means should be adopted to measure the steam supplied to the circulating-pump engine, or the quantity of circulating water, for enabling the experiments to be made more conclusive; and he could well understand the difficulties to be surmounted. He should like to know to what extent the inevitable

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waste of water from the glands of the piston-rods and feed-pumps had been noted and taken into account, as no mention of this point was made in the report. He had long looked forward to such trials as these in connection with the working of marine engines. For a number of years a great deal of time had been devoted to locomotives; and as England did the largest carrying trade in the world, he thought that more notice than hitherto should now be taken of marine engines, so as to give the rising generation of engineers an interest in the machinery placed under their charge; and it would be an inducement to them to work their engines in a more economical manner, and get the utmost work out of both engines and boilers, and prove to the ship-owners and others directly interested that these investigations would result in great benefit to commerce.

Mr. P. W. WILLANS considered Professor Kennedy was to be congratulated on having put before the Institution so complete a summary of the three trials described in this report. It was fortunate that all three came together in the same report, because it was interesting to be able to compare the results of trials in which the conditions were so different. The trial of the "Tartar" was especially interesting, because of the large quantity of water that was proved to have been present in the engine: he said proved, because it seemed hardly possible that any serious mistake could have crept in, although it seemed startling that so large a proportion of water was present.

As to the actual efficiency of the engines, he found on a comparison of the work done with the work which could have been done that the efficiency was almost exactly the same in all three. In the "Fusi Yama," taking the two extreme temperatures—the steam-chest temperature and the condenser temperature,—the quantity of water which would theoretically have been required per indicated horse-power per hour was 11·42 lbs., and the quantity actually used (Table 6, line 48) was 21·17 lbs., showing an absolute efficiency of 53·9 per cent. In the "Colchester," in which it was stated (page 224) that the engines were built more for speed than for economy, the water theoretically required was 10·71 lbs., and the water actually

used was 21·73 lbs., giving an efficiency of 49·3 per cent., as against 53·9 per cent. in the "Fusi Yama." In the "Tartar" the measured feed-water was at the rate of 19·83 lbs.; but it had been shown (page 234) that the heat from the coal could not possibly have evaporated more than 16·5 lbs. As a matter of fact 19·83 lbs. did go through the engine; and therefore the heat had been employed not altogether in making steam, but partly in making hot water. On the assumption that the boiler was giving the 70 per cent. efficiency mentioned in page 234, he found that 15·50 lbs. of steam and 4·33 lbs. of hot water must have passed through the engine per indicated horse-power per minute. That was neglecting the jacket water, which was a small matter—only 4 per cent. Supposing there had been the full 16·5 lbs. of steam, the engine efficiency would practically have been 53 per cent. Supposing that the engine took the 15·50 lbs. of steam and the 4·33 lbs. of water, the efficiency would be 54·3 per cent. of what the steam and water together could theoretically do. So that in the "Fusi Yama" and the "Tartar" the comparative efficiencies, calculated from the results given, were as 53·9 to 54·3. He should like to know what there was in the boiler to cause it to send over so prodigious a quantity of water; and taking this into account, it seemed astonishing to him that the engines did as well as they did. In any more of these trials that might be made, it would be of much interest if some kind of calorimeter on the boiler could be devised: not that there was any reason to doubt the figures now given, but it would be well to have an opportunity of corroborating them by a measurement of the water in the steam as it left the boiler. The Barrus calorimeter, though he had not himself tried it, he had heard well spoken of. A tank calorimeter, such as he had himself used, would test within half of one per cent.; but it was not very portable, and not easy to use on board ship. It was not necessary however to do the weighing while at sea; steam might be blown into a known weight of water in a vessel, and the water then weighed again on shore; the only observations necessary while at sea would then be the temperature before and after blowing the steam in.

The indicator diagrams illustrating the report he considered should be given separately both from the upper end of the cylinder

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and from the lower end, because he thought there was a great chance of the diagram from the under side of the piston differing considerably from that from the upper side, on account of the presence of water in the lower end of the cylinder. This was a point which he had noticed before in connection with some experiments of his own; but he had not then obtained what he thought absolute proof, and he now wished therefore to revert to the subject. He had lately been experimenting with a vertical compound engine that could be worked either condensing or non-condensing, in which water was found to accumulate in the lower end of the low-pressure cylinder when exhausting into the atmosphere. In designing the engine every precaution had been taken for enabling any water to drain away through the port; and from the section shown in Fig. 67, Plate 117, it would be seen that there appeared little chance of the water accumulating. It was found however that on cold days, and under conditions depending on a variety of small details, the water accumulated in considerable quantities; and then the engine gave out a comparatively small power. In Fig. 68 was shown one of the indicator diagrams taken when the water had accumulated; and in Fig. 69 was one taken when the water had been removed. Sometimes the engine would be running two or three hours without any water accumulating; and at other times he could hear the piston in the down stroke just touching the water in the bottom of the cylinder, but without causing a loud noise. It had therefore occurred to him that if a small copper steam-pipe were laid at C round the inside of the cylinder, in an annular recess formed for the purpose, it would be able to boil the water off; of course there was no steam coming into the cylinder through the pipe, which acted simply like a small boiler fitted into the recess in the cylinder bottom. On blowing steam through the pipe, it was found that the indicator diagrams immediately changed from Fig. 68, with only 19 lbs. initial pressure per square inch, to Fig. 69 with 25 lbs. initial pressure. Possibly a little of the difference might be caused by some distortion of Fig. 68, owing to the water in the indicator; but not much, because it was found that when the steam line was lowered in the low-pressure cylinder the exhaust line in the high-pressure cylinder was also lowered to correspond.

There was only about 4 inches length of pipe from the cylinder to the indicator, which was placed some distance from the point where the water was likely to collect, and just above the bottom of the cylinder, where it would be least likely to get water. As soon as ever the accumulated water in the low-pressure cylinder had been evaporated by the copper steam-pipe, which was done in about a quarter of a minute, the steam-line in the low-pressure diagram rose, and the exhaust line in the high-pressure diagram also rose. Therefore the difference in the low-pressure diagram was not all gain, because a good deal was taken off the high-pressure diagram; still a large margin of gain was left. It was also found in the dynamo which the engine was driving that the volts immediately went up and the current increased, to an extent corresponding with the increased power developed by the engine. As long as the water was present in the cylinder, its effect was seen in the lower compression curve in Fig. 68, showing that part of the steam during compression was condensed in raising the temperature of the water, and so lost as steam. When there was no water in the cylinder the compression curve rose in Fig. 69; it was then more nearly the compression curve of dry steam. A remarkable circumstance noticed was that, after the accumulation of water in the bottom of the cylinder had been driven off by the heat from the copper steam-pipe, and the steam had been shut off from the pipe, the diagrams continued to be the same as in Fig. 69, showing that the cylinder continued dry. It seemed as though, if the water once accumulated to a certain depth, it caused more water to accumulate; and if it were once reduced below that depth, the remainder boiled off, and no further accumulation took place. Theoretically no doubt, if the steam were used without much expansion, water was not likely to accumulate in the cylinder, unless it came in with the steam as priming water; but if on the other hand the steam were expanded down nearly to the back pressure, the probability was that water would then accumulate in the cylinder. In his own experiments the water did accumulate; but after once being driven off, it did not return. He could only account for this by the difference in the conducting power of the cylinder when dry and when water was in it;

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or possibly by the depth of the water preventing the bubbles of steam boiled off during expansion from ever reaching the surface of the water and escaping from it as steam until it was too late: the steam condensed owing to work done by the bubbles during expansion might remain in the water and might turn the scale. After the cylinder had once been dried by the copper pipe, the only way in which the water could with certainty be got to accumulate was by pumping cold water through the copper pipe; and when by this means the water had been once got to accumulate, the drying process had to be again resorted to in order to get rid of it. Professor Unwin had suggested trying whether increased external radiation would have the same effect; it had been found that by packing ice round the cylinder outside the same result was obtained, and when the water once accumulated, it could not be got rid of, except by means of the copper steam-pipe. The quantity of steam required in the pipe for drying the cylinder was a little more or a little less, according to the quantity of water accumulated in the cylinder; but the steam did not need to be kept blowing through the pipe; in fact the cost of the increased power was *nil* when the water was once removed. When exhausting into a condenser, he had thus far been unable to succeed in inducing accumulation of water in the cylinder: possibly because of the greater amount of re-evaporation during exhaust; or because of the smaller transmission of heat to surrounding bodies, due to the lower temperature of the cylinder. Although the size of the diagram in Fig. 69 was 30 to 40 per cent. greater than in Fig. 68, yet 15 to 20 per cent. or half of this gain was neutralised by the reduction of power in the high-pressure cylinder; and then the low-pressure and the high-pressure cylinder were about equal in power. The ultimate gain was about 6 to 10 per cent. in the power of the engine. This was not a result deduced merely from the indicator diagrams, but it had been proved by the work actually performed. The reason why he drew attention to this subject was that, where there was such a large quantity of water present in the cylinders, it must seriously affect the power of any engine; and diagrams taken from the under side of the low-pressure piston might show that the cushioning of the piston on that side was

more like that shown in Fig. 68, while on the upper side it might follow more nearly the true compression curve, as in Fig. 69. On this subject there was no doubt a great deal still to be learnt. In page 235 he noticed that the percentage of water calculated as present in the high-pressure cylinder of the "Tartar" strongly corroborated the conclusion that the steam was very wet; the percentage of steam in that cylinder was so much less than in either of the two other trials. It seemed extraordinary that only 45·2 per cent. of the feed-water should be present as steam in the high-pressure cylinder of the "Tartar" at the point of cut-off, in spite of its being a triple engine and steam-jacketed.

Mr. Henry Davey considered that in the report now presented engineers were furnished with everything they could desire in connection with these experiments, in the shape both of data and of calculations. The absence of steam-jackets on the two-cylinder compound engines in the "Fusi Yama" and the "Colchester" was a matter which he could not quite understand, inasmuch as it was seen from line 48 of Table 6 that in the "Meteor" triple engines with steam-jackets, and also in the "Tartar" triple engines with steam-jackets when the correction indicated in the report was made, the economy in the feed-water was something like 25 per cent. It seemed to him that probably an economy of about 12 or 13 per cent. or more might have been effected in the two-cylinder compound engines by the use of steam-jackets, so that instead of being 25 per cent. behind the triple they would be only half as much behind. Great diversity of opinion he was aware existed about the utility of steam-jackets on marine engines; but he failed at present to see why they should not be used. They were said to be troublesome at sea; but he could not see why they should be more troublesome at sea than on land. There would no doubt be difficulties in the way; but he thought a considerable economy might have been effected in the compound engines here referred to, if they had been steam-jacketed.

Another point that occurred to him was in regard to the effect of piston speed on the economy of the engine. Recently he had been

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making a feed-water trial with a triple-expansion engine running at the low piston-speed of only 140 feet per minute, and with an initial pressure of 130 lbs. per square inch above the atmosphere; and it gave results almost identical with those of the "Meteor." It was a steam-jacketed engine, and with the jackets in action the consumption of feed-water was 15 lbs. per indicated horse-power per hour, which was practically the same as in the "Meteor," where with an initial pressure of 134·4 lbs. the piston speed was 570 feet per minute. If there was any effect from the cooling which took place during exhaust, the time during which the cooling would continue must be greater in a slow-running engine than in a quick-running; the result however, as far as the consumption of feed-water was concerned, was identical.

Another curious point was that in his own trial, to which he was referring, the virtual steam-load on the low-pressure piston—that is, the whole power of the engine referred to the low-pressure piston—was 15 lbs. per square inch, whereas in the "Meteor" the corresponding load was 29·9 lbs., the initial pressure being almost the same in both cases. Therefore the expansion in his own trial must have been greater; and the economy due to the increased expansion appeared to have compensated for the lower piston-speed, so that the results in consumption of feed-water were identical. Thus with the same boiler-pressure, but with only one quarter the piston speed and with greater expansion, the same ultimate economy was found to be realised. There was evidently therefore a great deal to be learnt from engine trials carefully conducted; and such figures as these showed the great importance of the subject. The rough and ready trials that were made commercially did not give results from which such accurate deductions could be drawn as from the results of trials carefully conducted in the manner of those described in the report.

With reference to the question of water in the cylinders, although he had no data to corroborate in any way the argument adduced by Mr. Willans (page 248), he knew from general experience with steam engines that it did happen that water accumulated in a cylinder not exhausting into a condenser. In large horizontal

engines, even where the piston-rod was as much as two feet above the bottom side of the cylinder, water was often found to be coming out through the stuffing-box without any knock in the cylinder, when there was a leak in the stuffing-box: which must be the result he imagined of the steam itself being wet. But if the water accumulated in the cylinder sufficiently to fill the clearance between the piston and the cover, there was a distinct knock. It appeared to him that the great importance of steam-jacketing lay in its rendering the steam dry at the end of the stroke; and if the steam were made dry at the end of the stroke, or soon before the end of the stroke, then great economy resulted from the jacket. It was evident from the report that there must have been a considerable amount of priming water in the "Tartar." That was one of the great bugbears which had to be dealt with in experiments on steam engines; priming water might be present in the cylinder before it was detected. If some ready means could be devised for ascertaining the amount of priming water during the progress of experiments, it would be most valuable. At present a trial conducted with the greatest care and accuracy might be vitiated by the unrecognised presence of priming water.

The efficiency of the engines in the trials now reported was expressed in terms of the total quantity of heat received by the feed-water. This was probably the most reasonable way of expressing it, because all steam engines could then be referred to the same standard. But he could not help thinking that it would be further desirable if an expression could be introduced which would give an idea of something beyond. For it was obvious that if a two-cylinder compound engine were working with a boiler pressure of say 65 lbs., and a triple-expansion engine were using 130 lbs., it would be found that the efficiency of the latter, expressed in terms of the heat turned into work out of the total quantity of heat supplied in the feed-water, would be much better; but then the question was whether it was as much better as it ought to be. Hence the idea of expressing the efficiency of the engine in terms that included the range of temperature through which it worked seemed to him to be not so purely theoretical as it was sometimes imagined to be. It was true

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that such an expression was generally used under the form of what was known as Carnot's function; but instead of this he should prefer to express the heat utilised as a fraction of the heat practically available for the production of work. By way of illustration, if it were supposed that water was being drawn off from a tank through a pipe in the side of the tank and above the bottom, it was only the water above the mouth of the pipe that could be made use of; the remaining water below the pipe was of no use, and it did not matter how much water the tank could contain below the pipe, because it could not be made use of. So the heat below the normal temperature of the place where the engine was working was heat that could not be made use of; the only heat that could be made use of was what was above that temperature. Hence if the heat turned into work by the engine were 12 per cent. of the total quantity of heat taken up by the feed-water, and if the range of temperature through which the engine worked were such that the maximum work possible would be equivalent to 40 per cent. of the heat in the feed-water, then the expression for the practical efficiency of the engine would be $12 \div 40 = 30$ per cent. In this way the practical condition might be associated with the actual result obtained in the quantity of heat converted into work; and thereby more information would be furnished than was afforded by merely expressing the work as a fraction of the total quantity of heat.

In the two-cylinder compound engines of the "Fusi Yama" and the "Colchester," looking at the small extent of expansion in the high-pressure cylinder, he thought a better result might be expected if more expansion could be obtained in that cylinder. Better results were obtained in land compound engines having the same proportions of cylinders. That naturally arose from the fact that marine engineers had to produce a commercial result; it was not simply a matter of reducing the consumption of feed-water. If complications were introduced into the engine, they gave rise to difficulties which more than counterbalanced any gain in economy. Marine engineers therefore had to content themselves with simple valve-gear, which meant confining themselves generally to the ordinary link-motion and the ordinary slide-valve, and doing as well as they could with

these, having no separate expansion-valve on the different cylinders. Better results he was convinced could be obtained if separate expansion-valves were used; but he did not mean to say that it would be worth while commercially to use them; probably in practice it would not be found to be so. Nevertheless with compound engines working under the conditions described in the report, he thought that the better results obtained in land engines might render it worth while for marine engineers to turn their attention to getting more complete valve-gear for expansive working.

Mr. William Schönheyder suggested that the report on the "Fusi Yama" trial, which had been made in November 1888, should have been presented earlier by itself, instead of waiting for the two later trials. Progress was now made so rapidly that such a report was of very little use after twelve or eighteen months; future trials he therefore hoped would be described a little sooner. In all the three trials now reported he noticed that the steam for the circulating pump was taken from a separate boiler; but there were many marine engines in which it was taken from the main boiler; and as the power required for the circulating pump was often great, he hoped it might be possible in future cases to take indicator diagrams from the engine which drove the circulating pump, so as to ascertain what power was thereby added practically to the main engines. He also thought the report would have been more valuable if, in addition to the statements in figures, the indicator diagrams had also been combined, as had been done in the case of the "Meteor" (Proceedings 1889, Plate 48), in order that it might more readily be seen whether there was any loss due to wire-drawing and condensation between the cylinders, or to other causes. From line 44 in Table 6 it appeared that the amount of water evaporated per hour per square foot of total heating surface was 3·48 lbs. in the "Fusi Yama," and 7·39 lbs. in the "Colchester": so that the rate of evaporation in the "Colchester" was more than twice that in the "Fusi Yama." Thence it would naturally be expected that the efficiency of the boiler in the "Colchester" would be much less than in the "Fusi Yama"; but it was seen from line 58 to be not much less. What then was the good

(Mr. William Schönheyder.)

of all the figures given in the report? They seemed to him to be practically useless, and the report itself to be only a half-and-half sort of production. What he wanted was drawings of the engines and boilers, in order to find out what it was that caused the efficiency to be so different from what it ought to be; at present he considered the figures given were next to useless.

Mr. LAVINGTON E. FLETCHER wished to join in thanking Professor Kennedy for the trouble he had taken in conducting these marine-engine trials and in laying the results before the meeting; and hoped he should not be considered unmindful of the labour which the investigations and the report had entailed, if he asked for a little more information still. The proportion of steam accounted for by the indicator diagrams was given in the "Fusi Yama" without steam-jackets as 70·8 per cent. (page 211), and in the "Tartar" with steam-jackets as 60·3 per cent. (page 235). Having always been an advocate of steam-jackets, he did not understand how the loss of steam was greater with the steam-jacket than without it; and he should be glad if Professor Kennedy could offer some remarks on this point. It would also be of assistance in studying the report, he thought, if the "piston constant" for each cylinder were given, that is the horse-power exerted in the cylinder for every pound of mean effective pressure per square inch on the piston. Piston constants were very convenient in forming comparisons between different engines, as well as between the different cylinders in the same engine; for they showed the relative capacities of the cylinders, including the speed of piston; or in other words, they showed the comparative "piston sweep." In Table 6 the mean effective pressures per square inch in the several cylinders were given, as well as the total effective pressure when referred to the low-pressure cylinder. These figures were very valuable, and coupled with the piston constants would be found of considerable service in studying the results of different engines and comparing one with another.

Mr. FREDERICK EDWARDS, as superintendent engineer to the owners of the "Fusi Yama" and the "Tartar," said that the "Fusi

Yama" had been purchased and overhauled just before the trial now reported. The voyage during which the test took place was her first voyage under his supervision. The cylinders had not been re-bored, but the pistons had been fitted with new spring rings. In order as far as possible to ensure everything being in order, he had had the engines indicated, and had made some alterations in the setting of the slide-valves. Unfortunately the new spring rings in the pistons did not quite fit the worn parts of the cylinders, time being required for the cylinders to wear up to a good surface. The high-pressure cylinder was the worst, and the stiffness of the rings accounted for the difference in the powers as given in page 208. After a voyage or two the surfaces had now worked up to a first-rate condition, and the powers had become equal, the two cylinders together giving something like 450 indicated horse-power.

The "Fusi Yama" he believed was the first steamer that had been fitted with permanent tanks for measuring the feed-water. They were fitted above the engines, on a level with the tops of the cylinders; and the air-pump delivered into them. There was no objection to that arrangement; it worked well, provided the air pipe or overflow pipe stood a few feet above the tanks. It was also necessary of course to have a sufficient air-vessel on the delivery pipe, and then the extra pressure on the delivery valve made little apparent difference in the working of the air-pump. The discharge pipe from the tanks led directly down to the feed-pumps; consequently there was a pressure in the suction pipe, which he found always unsatisfactory in working, that is, if the pressure was at all great. In the present case the feed-pumps apparently filled right up with water, and no air got in to cushion the return stroke of the plunger; hence any leakage there might be round the plunger was of water, none of it was air. Consequently the pumps worked under an undue pressure; and in all future cases therefore he was satisfied it would be better to fix a third tank at about the level of the pumps, for them to draw from, and for the measuring tanks to drain into. When he had an opportunity, he should fit another tank below in the "Fusi Yama," and let the upper tanks drain into it; this would do away with the undue pressure or shock on the pumps.

(Mr. Frederick Edwards.)

He had since had another steamer, the "Olympo," also fitted with permanent tanks, as shown in Figs. 59 to 62, Plates 114 and 115. Here TT were the two rectangular measuring tanks, each of 100 gallons capacity and each draining into the reservoir R below. The arrangement of the pipes was as follows:—A the discharge from air-pump U to measuring tanks T; B suction from measuring tanks through reservoir R to feed-donkey and engine feed-pump P; C suction from hotwell W to feed-donkey and engine feed-pump P; D suction from measuring tanks or hotwell through valve-box to engine feed-pump; E suction from measuring tanks or hotwell through valve-box to feed-donkey; F suction from condenser to feed-donkey; G delivery from feed-donkey to boilers; H delivery from feed-donkey to high-pressure valve-box V; K delivery from feed-donkey to distributing valve-box S; L delivery from feed-donkey, overboard, and on deck, and to sanitary tank, and to fresh-water condenser; M delivery from feed-donkey to feed-heater; JJ overflow pipes from measuring tanks; Q discharge overboard from air-pump.

Objections had been raised against fitting permanent tanks, on account of the room they occupied; but he preferred the tanks to meters, because meters had an error to be allowed for, and it was preferable to work if possible without unnecessary errors. In an ordinary cargo steamer the question of sacrificing space in order to make room for permanent measuring tanks did not arise, because in order to meet certain requirements of the tonnage laws the engine-room had to be made larger than otherwise necessary. But in full-power steamers it had appeared to him to be impossible to find room for the tanks, until it had been suggested to him by Mr. Macfarlane Gray that they might be used ordinarily for oil storage. That was a good idea, and he was grateful for it. The tanks were wanted only occasionally for testing the consumption of water, during which time the oil could be left in the drums; and the tanks must of course have man-holes, through which the grease could be cleaned out before they were used for feed-water measurement. While they were being used as oil tanks, the connections with the feed-pumps should be broken or entirely removed. The report from the last steamer fitted with these permanent feed-measuring tanks showed a consumption he believed

of about 14 lbs. of water per indicated horse-power per hour; but the evaporation was low, thus showing clearly that the engines were giving good results, but that the boilers were not as efficient as they should be, and that in order to obtain better results attention must be directed to the boilers rather than to the engines. In case of the consumption being more than it should be, the tanks gave the means of ascertaining in a short time where the fault lay, whether it was in the engines or in the boilers; and this was a great convenience.

With regard to the trial of the "Colchester," he wished to mention that it was owing to the prompt orders given previously to the commencement of the trial and in the middle of the night by Mr. George Derry, the marine superintendent at Parkeston Quay, Harwich, that the trial had been saved from being a failure; and the Committee were much indebted to him for having certain necessary alterations made.

With regard to the "Tartar" trial, the excessive priming mentioned in the report was certainly astonishing. During the trial there had been no indication of priming, beyond the little water that was coming out of the intermediate cylinder through the indicators. When the "Tartar" was built about three years ago, he had attended the trial then made; that was the time when priming would be expected, but there had been absolutely no sign of it whatever. The proportion of steam space in the "Tartar" boilers, shown in Plate 113, was greater than in any of the other steamers under his care. During the trial there was no discharge of water through any of the escape valves on the cylinders, nor was there any knocking heard in the cylinders, nor any other sign of priming; and it was difficult to understand how the water could have been carried over in such large quantities. The steam stop-valves were situated on the extreme end of each boiler, and were fitted with internal steam-pipes. This matter he considered important, because, if these boilers were priming, then in his opinion there could be very few boilers that did not prime, and prime badly. The height from the top of the combustion chamber to the top of the boiler was more than a third of the diameter of the boiler; and he had boilers in which it was a good deal less than a third, and yet there was no sign of priming. He had also seen

(Mr. Frederick Edwards.)

drawings of boilers in which this height was less than a quarter of the diameter, and he had been assured by the builders that when working at 160 lbs. pressure there was no priming. He had looked through the log books of the "Tartar," and could find no record of any trouble with water in the cylinders. It was important to bear in mind that the only indication there had been of priming during the trial had been in the intermediate cylinder; and as far as he could gather, in triple-expansion engines the signs of priming almost always showed themselves in the intermediate cylinder. There was only one exception that he knew of, where damage or trouble had arisen from priming in a high-pressure cylinder; in that case the top of the cylinder and cover had been broken clean off by priming, and had to be patched up in order to send the vessel on her voyage; but then he believed the high-pressure cylinder had been fitted with a piston-valve and had no escape-valves. On the other hand, he had had two if not three cases, where the damage had been done by priming in the intermediate cylinder. The reason of this he did not understand; and he should be glad if any one could throw light upon it.

During the trial of the "Tartar" he had tried to get diagrams from the feed-pump and the circulating pump, but had found it was impossible to do so for want of room while the rest of the observations were all being made. Therefore after the ship sailed on her next voyage he had had them taken by the chief engineer, and they were shown in Figs. 63 to 66, Plate 116. Although the working boiler-pressure at the time was not more than 143 lbs. per square inch and the speed only 62 revolutions per minute, the indicator diagram, Fig. 63, showed that a pressure of as much as 220 lbs. per square inch had been required in the feed-pump for forcing the water into the boiler. As the pump was single-acting, $3\frac{1}{2}$ inches diameter and 27 inches stroke, making 62 effective strokes per minute against a mean pressure of 98 lbs. per square inch, it was consequently requiring 4 horse-power to drive it. The circulating-pump pressure was also high, Figs. 65 and 66; and mounted up much higher still when the snifting valves were shut, Fig. 64, and there was no air to cushion the pump. Consequently he had given instructions for diagrams to be taken with the snifting

valves shut, Fig. 64, then partly open, Fig. 65, and then full open, Fig. 66, in order to show the difference in the pressures. The circulating pump was double-acting, 11 inches diameter with rod $2\frac{1}{2}$ inches diameter, and 27 inches stroke, making 62 double strokes per minute. When the snifting valves were shut, the mean pressures on the top and bottom of the circulating-pump piston were respectively 14·7 and 12·3 lbs. per square inch, and the horse-power consumed was 10·5; when the snifting valves were one-quarter of a turn open, the mean pressures were 13·7 and 12·2 lbs. per square inch, and the horse-power 10·1; and when the snifting valves were full open, the mean pressures were 11·9 and 11·5 lbs. per square inch, and the horse-power 9·2.

Mention had been made in the report (page 230) of the frequent intervals at which the samples of furnace gas had been collected and the chimney temperatures read; and he was glad that attention had been drawn to this portion of the work, because it had involved throughout the whole trial unremitting care and watchfulness on the part of Mr. Wilson, who had been an example to all the staff of observers. As to the results of the "Fusi Yama" trial not having been supplied sooner (page 255), he thought if any Member who was in a hurry for the information would kindly help to work out the results it would be much better than complaining; and the Committee would be glad of any help that could be given.

Mr. J. F. L. Crosland considered that, while drawings of the boilers would be useful in other respects, the information already given in Table 6 was sufficiently complete for enabling some reasonable idea to be formed as to why there was so much difference in the rate of evaporation of feed-water per square foot of total heating surface per hour (page 255), namely 4·49 lbs. in the "Meteor," 3·48 lbs. in the "Fusi Yama," 7·39 lbs. in the "Colchester," and 4·13 lbs. in the "Tartar." From line 37 in Table 6 it was seen that the coal burnt per square foot of grate per hour was 19·25 lbs. in the "Meteor," 18·98 lbs. in the "Fusi Yama," 26·1 lbs. in the "Colchester," and only 11·93 lbs. in the "Tartar"; and it appeared to him that the much greater rate of consumption of coal

(Mr. J. F. L. Crosland.)

per square foot of grate per hour in the "Colchester" fully explained the higher rate of evaporation in that trial per square foot of total heating surface, and he thought the information supplied in Table 6 was therefore ample. The results of the trials now reported were to himself a source of great gratification, because they completely dispelled the illusion hitherto prevailing as to the special economy of marine engines. The public had for many years been given to understand that marine engines worked at what many engineers considered, with the conditions given, impossible rates of coal consumption per indicated horse-power per hour, such as $1\frac{1}{4}$ lb. The present report had now given some real facts on this subject, showing that the consumption with two-cylinder compound engines was 2·66 lbs. and 2·90 lbs.; and even with triple-expansion engines, with 150 lbs. boiler pressure and with the most modern improvements, excepting only that there were no special expansion-valves, the consumption of coal had not been brought down lower than 2·01 lbs. in the "Meteor" and 1·77 lbs. in the "Tartar."

Mr. CHARLES E. STROMEYER considered that, so far from the present report being an incomplete one, it was about as thorough a report as he had ever read. An enormous amount of information was condensed into it, in a form which ought to prove of great assistance. In response to the appeal made at the end of the report for suggestions as to improvements in the instruments to be used for such trials, it seemed difficult enough to propose anything that had not probably occurred already to the Committee. When he first went to sea many years ago, he had tried to make accurate trials which were to extend over many hours, and he had found the spring balances unsatisfactory for weighing the coal, because the pointers would keep moving up and down while the coal was being weighed. He had therefore substituted a steelyard, which was pretty steady in its readings, even when there was a considerable up and down motion of the vessel. As long as the water was smooth, it did not make any difference which instrument was used; but in a rough sea the steelyard answered better than the spring balance.

In the trials now reported the temperature of the discharged condensing water did not appear to have been measured; it would be a valuable addition he thought if that could be given, and also, as suggested in page 236, the quantity of water which was discharged. It was therefore desirable in his opinion that the dimensions of the circulating pumps should be given; for although it was true that the quantity of the condensing water could not be measured exactly in that way, yet he saw no other means of measuring it. Considerably more water he believed actually passed through the circulating pump than that due to the volume of the pump and the number of strokes per minute. At any rate this additional information would be some sort of guide as to the quantity of condensing water used, and might throw some light on the question of condensation.

It might also be possible to measure the quantity of air that was mixed with the steam as it came from the boiler. In the first ship he was in he had measured it by leading condensed boiler-steam under an inverted bucket, which had been filled with water and placed in a tub of water; all the air which was previously in the steam of course gathered in the bucket, and by noting the time it took to fill the bucket with air, and comparing it with the time required to fill the same bucket with condensed water, he had been able to estimate how much air there was in the boiler. As the snifting-valves of the air-pumps and feed-pumps were all open to the atmosphere, it was clear that a large amount of air must have been driven into the boiler. The estimate so obtained of the volume of air was that it equalled the volume of the feed-water. Air he felt sure collected round the tubes in the condenser, and hindered the steam from reaching the cooling surfaces quickly and from condensing; it thus caused the vacuum to be reduced more than was perhaps imagined.

With regard to coal dust and soot in the boiler tubes, it was of course difficult to measure these; still they were not products of combustion, and therefore ought not to be included in the coal consumed or in its carbon value. If, instead of using coal which produced much smoke and a lot of fine dust, a better coal were used, a better evaporation per pound of coal would be obtained from the boiler. The actual efficiency of the boiler was accordingly not given

(Mr. Charles E. Stromeyer.)

in the report; what was there given as the efficiency of the boiler was really the efficiency of the boiler and the coal combined, and not of the boiler by itself. Although the tables of analyses of the funnel gases were very complete, they might be improved he thought if the temperature of the uptake, corresponding with each analysis of the products of combustion, were also given. It was true that the average temperature from all the observations was stated; but if it could be given for each analysis a good deal of useful information would be obtained, especially if also the differences of pressure or the draught pressure, as shown by the water gauge, could be stated. These were points about which little was as yet known, and the value of the report would be much increased if they could be added. He had been looking into this very matter with the intention of finding out if possible what the temperature was in the combustion chamber; and by assuming a certain coefficient for transmission of heat through the tube surface, he had arrived at the conclusion that the temperature in the combustion chamber was generally about 2,000° Fahr. higher than in the uptake, taking into account the amount of tube surface, and also the weight of the gas which passed through per hour. But on calculating the temperatures by that plan, he had arrived at the conclusion that the temperature in the combustion chamber must have been 7,670° in the "Fusi Yama," which seemed impossible, while it was 2,550° in the "Colchester" and the "Tartar." The only explanation which occurred to him was that possibly there might have been a mistake in observing the temperature of the gases in the uptake. An idea of the importance of this subject would be obtained if it was borne in mind that the relation between the quantity of air and the heating surface was pretty nearly the same in the "Fusi Yama" and the "Tartar"; yet in the "Tartar" there was a difference of only 115° between the temperature of the water and the temperature of the uptake, while in the "Fusi Yama" the difference was about 274°. This great difference seemed to point to something being wrong in the "Fusi Yama," but he did not know what it was.

The draught was another subject which might perhaps be thoroughly explained, if the particulars of the temperatures in the

uptake were given: namely the influence of the cold air when it mixed with the hot gases at the time of opening the fire-doors for firing, or the influence of the cold air getting in through the fire-bars. Supposing 10 per cent. more air had been admitted than was necessary for combustion, then not only were the gases cooled in the combustion chamber, but also their volume was increased, and therefore the speed with which they passed through the tubes was increased, whereby the efficiency of the tube surface was reduced: at the same time the volume of the gas which went away was larger, so that there was a possibility of an addition of cold air in the furnace producing an increase of temperature of the waste products.

The trial which he had himself made many years ago had been carried out under unfavourable conditions, because he was then only third engineer and could not get the chief or the second to help him with it, and he had had to do all the work himself, continuing the trial for twelve hours during three watches; but during his own watch he had been able to take a considerable number of indicator diagrams, and the results were interesting as showing the influence of cleaning fires. There were six furnaces. In one watch he had noticed that the engines started with 570 horse-power; the fires were then cleaned, and the power dropped to 505. It took an hour from the commencement before it rose again to 570; then it was kept at 600 for the rest of the three hours of that watch. In another watch it had started at 570 and dropped to 515, and had taken an hour and a half to rise to 570; after which it remained stationary at 580 horse-power for the rest of the watch.

Mr. G. R. BODMER considered it remarkable that, although the diameters of the high-pressure cylinders of the three engines were not very different, yet there was so great a difference in the initial condensation, or the number of heat-units given up to the body of the piston and the cylinder walls and covers, previous to cut-off. Curiously enough the number of heat-units lost by initial condensation was much greater in the high-pressure cylinder of the "Tartar" than in the larger high-pressure cylinders of the two other engines. In the "Fusi Yama" he calculated that the number of heat-units lost

(Mr. G. R. Bodmer.)

per single stroke in the high-pressure cylinder by initial condensation up to the point of cut-off was only 125·8, while in the "Colchester" it was 523·6, and in the "Tartar" it was as much as 841 after allowing for priming. Notwithstanding this great loss, it was seen from line 48 in Table 6 that the "Tartar" was nevertheless the most economical of the three in the quantity of feed-water used per indicated horse-power per hour, even irrespective of the allowance that was made (page 234) for priming. It thus appeared that the number of heat-units lost by initial condensation in the engine of the "Fusi Yama" was much less per stroke than in the more economical triple-expansion engine of the "Tartar." From certain other experiments he had been trying to arrive at some rule which might be approximately satisfactory for the amount of heat lost per stroke by initial condensation; but he confessed that the figures now presented quite upset any attempt to formulate the results. Although there seemed at present no sort of consistency or relation between them, it would be interesting if the clearance surface in square feet, which was given in Table 6 for the "Colchester," could also be added for the other engines.

In regard to the absence of any satisfactory method for measuring the quantity of condensing water, he ventured to suggest, though with some diffidence as he had not had anything to do with the trials, an instrument for gauging water which had recently been devised by an American, Mr. Clemens Herschel, who called it the Venturi meter. The principle of the instrument was that the velocity of flow was calculated from the difference of pressure at two points in a pipe having its bore relatively much reduced at one part; one point of measurement was where the sectional area was greatest, and the other was at the most contracted part. It was said to give accurate results, but he did not know how far that was the case. It had occurred to him that it might be worth while to try such an instrument, and see whether it would be possible to use it for measuring the circulating water.

Mr. CHARLES J. WILSON said that, as the results of these trials were calculated on a heat basis, the analyses of the coals and gases

were of considerable importance. In order therefore to ensure the accuracy of the figures, precautions had been taken which did not appear in the report. The whole of the coal samples from each trial had been reduced to a fine powder before a portion was taken for analysis. The analyses given in the report had been made throughout in duplicate, separate quantities being weighed for each of the two. Hence any want of uniformity in the samples analyzed would have appeared as a discrepancy in the analyses; but as a matter of fact the analyses agreed precisely. In the case of the furnace gases, every precaution had been taken to prevent air from leaking in, and to ensure collecting a really representative sample in each case. The gas pipe was completely exhausted of air, by drawing off a large volume of furnace gas before a sample was taken; and the gas after it was collected came in contact with nothing but dry mercury and dry clean glass. When it was taken to the laboratory to be analyzed, the determinations were again all made in duplicate. He therefore felt confidence in the figures which he had given in the report.

Mr. John Phillips considered the boiler was not to be blamed at all in the case of the "Tartar"; and he thought it had really produced all the steam that it was credited with. The engines appeared to have been working with too small an amount of power for them to work economically. From Table 6 he found that the indicated horse-power per square foot of grate area was only 6·75 in the "Tartar"; while in the "Meteor," which was also a triple-expansion engine, it was 9·6. Then looking at the capacity of the cylinders per horse-power—that is the aggregate volume swept through per minute by the pistons, taking the aggregate area of the three pistons in square inches and the piston speed in feet per minute—in the "Meteor" this capacity amounted to 1,743, and in the "Tartar" to 2,548; the "Meteor" thus had about two-thirds the piston displacement of the "Tartar" per horse-power per minute. Moreover the mean pressure referred to the low-pressure cylinder in the "Meteor" was 29·9 lbs. per square inch, while in the "Tartar" it was only 19·8 lbs. per square inch. Hence the cause of the great

(Mr. John Phillips.)

amount of water used in the "Tartar" lay in the endeavour to get a small amount of power out of a large engine. Moreover, while the boiler pressure in the "Meteor" was 145·2 lbs. per square inch, the initial pressure in the high-pressure cylinder was 134·4 lbs.; whereas in the "Tartar," with the boiler pressure of 143·6 lbs. per square inch, the admission pressure in the high-pressure cylinder was only 121·4 lbs., showing that there must have been a large amount of condensation between the time of the steam leaving the boiler and its admission into the cylinder. With such large boiler-power in proportion to the small quantity of work done by the engine, it seemed to him simply impossible that the boiler could prime, and he had never known of a boiler priming under such conditions. The work the boiler was required to do was exceedingly small for its heating surface or fire-grate area.

Mr. CHARLES E. COWPER, referring to the complaint (page 255) as to the delay in reporting the "Fusi Yama" trial, thought it was much better to have these three trials reported together, because the figures could now be more conveniently compared, and the subject was thus rendered much more interesting. The Institution he considered was to be congratulated upon having such an excellent report upon engines doing practical work. In the endeavours which engineers of the present day were making to investigate the real condition of the steam—or rather of the working mixture of steam and water—in the cylinder of the steam engine, any facts bearing upon the important subjects of cylinder condensation and re-evaporation were of great interest. Looking at the figures giving the proportion of steam accounted for by the indicator diagrams, and the "missing quantity" or percentage present as water, it would be noticed that the steam decreased from the cut-off in the high-pressure cylinder to near the end of the expansion in the low-pressure cylinder, and the missing quantity or water increased, both in the "Fusi Yama" (page 211) and in the "Colchester" (page 223), these engines being not jacketed; whereas in the "Tartar" the case was reversed (page 235), the steam increasing and the water decreasing, which was probably owing to the steam-jackets on the intermediate and low-pressure cylinders.

The high-pressure cylinder of the "Tartar" was not jacketed in the trial (page 232); that would probably account for a large amount of initial condensation in the high-pressure cylinder. In the "Meteor" trial (Proceedings 1889, page 245), the high-pressure cylinder being steam-jacketed, it would be seen that the quantity of steam at the beginning and at the end was nearly the same, namely 77·1 per cent. of steam after cut-off in the high-pressure cylinder, and 75·3 per cent. near the end of expansion in the low-pressure. He should therefore like to know whether Professor Kennedy considered that the difference between the "Meteor" and the "Tartar" in this particular was accounted for by the steam-jackets. For comparison he might mention two other instances that he was acquainted with—one a slow-working pumping engine, and the other a quick-working engine of Mr. Willans's, the former being steam-jacketed: in the slow-working jacketed engine it had been found that the percentage of water diminished continuously to the end, until the final measurement gave only a small proportion of water; while in the quick-working unjacketed engine the proportion of water continuously increased all through to the end.

In regard to the several sets of indicator diagrams not having been drawn out in a combined form (page 255), as had been done in the case of the "Meteor" (Proceedings 1889, Plate 48), possibly it had been thought wiser not to do so, because there was always a difference of opinion as to the correct mode of combining indicator diagrams. In a previous discussion (Proceedings Inst. C.E. 1889, vol. xcix, page 235) he had himself suggested that it would be highly advantageous if some method of combining could be agreed upon, so that all indicator diagrams from compound and triple-expansion engines might be combined in the same way; useful comparisons could then be made. He would now further suggest that a method should be agreed upon for calculating efficiencies, in regard to which the same divergence of practice prevailed. As the Institution of Mechanical Engineers had appointed Research Committees, they might well appoint a committee which could settle a standard system that all might adopt, in the same way as the British Association had determined a standard system of

(Mr. Charles E. Cowper.)

electrical units. He also suggested that the Research Committee on the value of the steam-jacket might make some experiments with jacketing at different temperatures with different pressures of steam. It appeared to him that the jackets on the intermediate and low-pressure cylinders of the "Tartar" had not been so efficient as they might be, because the steam in the jackets had been reduced in pressure and therefore in temperature.

Mr. DAVID JOY said the plan here adopted of adding together all the indicator diagrams and then averaging them to get a mean result did not seem to him at all satisfactory, because it did not really give the best that the engine was capable of; the whole result was a mixture of the top and bottom ends of the cylinders. It appeared to him that it would be preferable to have one of the best diagrams from the top and bottom separately of each cylinder; then it would be seen what the engines were doing at their best. It seemed to him a matter of regret that such elaborate experiments should have been carried out in what he thought were such ordinary ships; for he considered that two-cylinder compound engines were now really obsolete for marine purposes. It was very desirable in his opinion that trials should be made on some of the highest-class boats, so as to show the best that could now be done, and not merely what could be done ordinarily; and he thought he saw his way to getting the use of some 3,000 horse-power engines of the most recent kind, which had been running for only a short time and he believed would give fine results.

Mr. ALFRED WATKINS thought it curious that the higher-class engines in the "Tartar" apparently did not give a result in any way superior to the engines in the "Meteor," which were professedly not built for economy. The remark made (page 268) about the poor result in the "Tartar" engines possibly not being due to priming he thought was true, because he believed experience proved that unless an engine was worked at full power the benefit expected from it was lost. It was no use designing an engine to work with high-pressure steam, and then working it at low pressure; it would not

give nearly such good results as an engine designed to work with low-pressure steam; this he supposed was obvious. If the reason of the "Tartar" not giving a better result was in the boilers, supposing the measurement of water supplied to the boilers to be correct, it would be well to try the result of working with one boiler only, instead of two. The coal burnt per square foot of grate in the "Tartar" was little more than half that burnt in the "Meteor," and yet the "Meteor" boilers could not be said to be overworked during the trial; for during one half of her regular work they were worked with forced draught and generated 50 per cent. greater power than during the trial, during which the forced draught had not been used. According to the report it therefore appeared to him that there had been a waste of money and space in the "Tartar" by giving her two boilers, when one boiler would have been as effective. The report also showed that these lightly worked boilers primed heavily, while similar boilers worked twice as hard did not prime: a result which was, to say the least, surprising.

Mr. John G. Hudson believed the surface condensers for marine engines had hitherto been almost always designed by rule of thumb; and the present trials went so far towards supplying the means of arriving at a more rational method, that he ventured to ask for the additional information needed for the purpose. If the temperatures of the inboard and the overboard condensing water could be stated, it would thence be known how much water was passing; and if also such particulars were given of the condenser as would allow the speed of the water over the surface to be ascertained—namely whether the water passed through the tubes or around them, whether it entered at the top or bottom of the condenser, the number of currents, and the number and bore and length of the tubes in each section—there would be the means of arriving at the laws governing the transmission of heat through the condenser tubes, and of designing surface condensers in accordance with them. The report already dealt with the generation and use of the steam, and its condensation would complete the cycle.

Mr. J. MACFARLANE GRAY said that in engineering there were many constants used, some of which were mainly rules of thumb, but were nevertheless useful. The experiments which had now been made might be utilised he thought for verifying those constants. For instance, Rankine's rule for the number of heat units that would pass through a square foot of heating surface, such as that in boilers and tubes, was the square of the difference of temperature divided by from 160 to 200. Another rule made it proportional only to the simple difference of temperature, instead of to the square of the difference. In entering upon a set of experiments it ought to be understood at the outset what were the definite objects worked for; and then all the particulars for those objects would be given in the report. He had tried to verify the above rule, but the essential particulars were not given; and assuming them on the best theory he could think of, the report gave very inconsistent results. There was a great deal of information to be got from the report as it was, and everyone could get from it something useful for himself. He suggested that it would be better if the statement of the particulars respecting the trials and the engines were arranged somewhat differently. By arranging them geographically according to a standard system, the particulars of a large number of engines could all be got into a small note-book with only a few figures. This could be done by dividing a card into spaces, like the panes of a window, with dark and light lines, and writing in each space what was wanted to be there recorded. Then by recording always the corresponding particulars in the same spaces on each successive page, there was no need to encumber the record with words. In that way all the particulars of an engine could be put upon the back of an address card, and it was then far easier to find anything that was wanted.

Mr. G. S. YOUNG suggested that the capacity of the steam space in the boilers should be given, as that was an important matter in designing boilers. If there was priming to such an unusual extent as stated in the triple-expansion engine, it could be discovered by a comparison of the saltness of the water in the boiler and in the

hot well. As a rule, if a marine boiler primed to the extent of 20 per cent. of the mixture of steam and water passing off to the engines, the salt so mixing with the condensed steam in the hot well could be detected by the ordinary salinometer; or, if that was not sufficiently accurate, a chemical analysis of the water in the boiler and the water in the hot well would demonstrate whether the water from the boiler had all passed through the engine in the form of steam or whether a part of it had gone through as water. Such a test, combined with other means, would help to settle the question as to whether priming was actually going on.

Mr. Leslie S. Robinson, referring to formulæ in use for calculating the draught which a certain height of funnel would produce, observed that in the report the vacuum in the funnel was given, and it would be interesting if the vacuum could also be taken in the ash-pit or as near the furnace as possible. It would then be seen what force of draught there was in the furnace.

Another interesting point, upon which he hoped Professor Kennedy would be able to throw some light, was the great difference in the proportion of heating surface to grate area in these boilers (Table 6, line 15). Three of them had the usual proportion of about 30 to 1, namely 32 and $32\frac{1}{2}$ in two cases and $26\frac{1}{2}$ in the other; but in the "Fusi Yama" the proportion was 43·4 to 1. In some boilers that he knew of, the proportion ran as high as 60 to 1. If any information could be given with regard to the difference produced in the efficiency of a boiler by an increase in the proportion of heating surface to grate area, it would be of great service to engineers generally.

Mr. W. Worby Beaumont pointed out that, although in the jacket on the high-pressure cylinder of the "Tartar" the steam was stated in page 232 to have been shut off, yet further on in the same page it appeared that steam enough leaked through into the jacket to give a pressure varying from zero up to more than 50 lbs. per square inch. There would thus be a difference of temperature between the steam inside the cylinder and the vapour outside in the jacket, varying from perhaps 60° to considerably over 100° Fahr., which seemed to be an

(Mr. W. Worby Beaumont.)

unfavourable condition for that cylinder to work under. Was there any other evidence than that obtained from the analysis of the gases, from the water in the indicators, and from the estimation of the indicator diagrams, upon which it had been decided that so large an amount of priming must have taken place? There was certainly great difficulty in believing that the boiler would evaporate as much as 13 lbs. of water per lb. of coal; but he hardly understood how, under the various conditions reported, there could have been such a large amount of priming. Mention was made in page 224 of the weather having been sufficiently rough to cause the engines to race a little during the latter part of this trial; and it occurred to him that a rough sea might have caused the water to be thrown about in these boilers, and that, as in some of the rapid-circulation boilers, this might cause a good deal of water to be carried away as spray with the steam; but there was no adequate proof that such priming occurred throughout the trial.

The PRESIDENT, referring to the remark (page 271) that it would have been better to work the "Tartar" engines with one boiler than with two, said this had not held good in practice with locomotive engines. There, the more heating surface could be got into the boiler, the less coal would be burnt to do a given amount of work; and it appeared to him that the same might hold good with marine engines as with locomotives. If it were attempted to run a given weight of train with an engine having a small boiler, it would require more fuel per mile to do the work than in the case of another engine with cylinders of the same size but having a larger boiler and burning the fuel more slowly.

Marine engineers had lately been going in for triple and quadruple expansion engines; but what he desired to impress upon their consideration was the importance—indeed the absolute necessity—of getting something like uniformity in the work done on each crank. This had not been realised hitherto; and in this respect he did not know that he had ever seen what he could call a perfect set of indicator diagrams. In this connection he had already made some remarks upon the "Meteor" trial at the previous meeting (Proceedings

1890, page 93). From the present report it appeared that in the "Fusi Yama" (page 208) the high-pressure cylinder did 45·3 per cent. of the work and the low-pressure 54·7 per cent. The "Colchester" (page 220) was the nearest to uniformity, doing 48 per cent. in the high-pressure cylinder of each engine, and 52 per cent. in the low-pressure. In the "Tartar" (page 231) there was only 26·1 per cent. in the high-pressure cylinder, against 37·6 in the intermediate and 36·3 per cent. in the low-pressure cylinder. So unequal a distribution of the power could not be good either for the cranks or for the engine. If such conditions were allowed in a locomotive, it would never be able to run at all; the driver would not be able to stand on the foot-plate, but would be thrown off the engine. There ought to be some provision in marine engines he considered, by means of pressure-gauges on the receivers and on the cylinders, and by reducing valves, so that the steam could be throttled in its passage from the boiler to the high-pressure cylinder and thence to the other cylinders, in order that something like uniformity of power might be obtained in each. There must necessarily be great difficulty he was aware in accomplishing this object, because the condenser maintained a uniform vacuum, whatever the power; and therefore the problem to be dealt with was an intricate one. He had no doubt however that it would be solved as thoroughly as it ought to be with the marine engine, and almost as completely as had already been done with the pumping engine. In the latter it could be accomplished perfectly, the work being fairly constant.

Professor Kennedy, in reply, noticed that Mr. Carbutt (page 244) not unreasonably thought the steam for the circulating-pump engine should in fairness have been supplied by the main boiler in the case of the "Colchester." The fact was that the pipe arrangement was such that this could not have been done without at the same time sending steam from the main boiler to the dynamo engine.

In reference to Mr. Hallett's remarks (page 246), he could not say what the waste of water from the glands had been, but only that there was nothing exceptional about it.

(Professor Kennedy.)

It had been suggested by Mr. Fletcher (page 256) that the piston constant for each cylinder should be given; and he should have much pleasure in adding these figures to Table 6. The discrepancy between the amounts of steam accounted for by the indicator diagrams in the "Fusi Yama" and in the "Tartar" he thought could only be properly explained if the cause of the large steam or water consumption by the "Tartar" were known. Of this he should have something to say further on. The same remark would apply also to the difference between the "Meteor" and the "Tartar," alluded to by Mr. Cowper (page 269).

Passing now to the more general questions raised by the report, he confessed that he was still in considerable perplexity in reference to the water consumption during the "Tartar" trial, about which so much had been said. Having himself no figures in reserve beyond those given in the report, he therefore could not add anything to what was there said. He felt quite as much as other speakers the great difficulty of supposing that by any possibility such a large amount of priming could have occurred. There were none of the usual signs of priming, except the apparent wetness of the steam in the intermediate cylinder; while the supplementary feed-water put into the boiler was not remarkable in any way. In view however of the contention of some speakers, that the water which went into the boiler was really evaporated, he must point out that, whatever might be the real explanation of the matter, this one could hardly be true. He thought himself that nothing could be more certain than that the boiler did *not* turn into steam all the water which passed through the feed tanks; and although he had endeavoured to make his reasons for this conclusion plain in the report, he would here repeat them. If all the feed-water had been evaporated, the boiler efficiency must have been 84 per cent. of the whole calorific value of the fuel. The furnace gases were known to have carried away from 21 to 23 per cent. of that heat, which added to 84 made 107; and the further losses by radiation would bring the total heat accounted for in this case to 15 or 20 per cent. more than the amount corresponding with the theoretical calorific value of the coal: which he need not point out was a result physically impossible. Whatever happened to the

water therefore, it was not wholly turned into steam. The result of the first working out of the figures had been such a complete puzzle to him that he had gone through them all again, in case there might be some mistake, but had been unable to find any. He had hoped that some suggestion would be made in the discussion as to why or how such an exceptional amount of water should have passed through the boiler without evaporation; but thus far no suggestion had been made. Even Mr. Edwards, whose opinion he should certainly trust more than his own in such a matter, and who objected so strongly to the idea that there was any priming, had said (page 260) that the place where water showed itself in the case of priming was generally the intermediate cylinder; and oddly enough this was the very place in which water had been met with in the "Tartar." He confessed however that he was himself not at all satisfied with the priming explanation, but was unable to suggest anything better.

It had been pointed out in the report (page 224) that the "Tartar" had been tested quite light; she had no cargo on board, nothing but water ballast, and this of course accounted for her requiring so little driving power. No objection had been taken at the time to the trial being made on a light ship, nor until after the results were known, when it was regretted that the ship had not been fully loaded. He had expected to be asked why she had been tested under such conditions; and although the question had not actually been put, he would answer it. The reason was the simple one that it was with great difficulty the Committee had succeeded in getting steamers which could be tested at all; and therefore they were very glad to avail themselves of the opportunity of testing such excellent machinery as that of the "Tartar," even if the circumstances were not such as to bring out its highest economy. The arrangements for the trial had all been practically completed before it was known that the run would be made quite light; and as no objection was raised by the engine builders' representative on board, it was not thought proper to postpone the trial, and so waste much laborious and expensive preparation. When the "Meteor" trial was discussed a year ago, several enthusiastic offers had been made of steamers to test, but up to this date he had heard nothing further about them.

(Professor Kennedy.)

The objection to the trials, that they were carried out in such ordinary steamers (page 270), he thought was really not justified. The "Tartar" was a very fine example of a triple-expansion engine made by one of the best firms. The "Colchester" engines also were quite new, although they did not happen to be triple-expansion.

As to the question of determining the water in the steam as it left the boiler (page 247), of course no weighing apparatus sufficiently delicate for this purpose could be applied on board a steamer. The superheated-steam calorimeter of Mr. Barrus, which had been mentioned in this connection, was very ingenious. It seemed to him however that the formulæ used with it required much more convincing experimental proof than they had yet received, before they could be freely accepted. He also understood that its instrumental correction for radiation amounted in all cases to a very large percentage of its whole reading, which if true was of course a serious drawback. The action of this calorimeter, as he understood it, rested upon the assumption that, immediately steam reached a temperature even one degree above that of saturation at its particular pressure, it became superheated and could be treated as if it were a perfect gas. This assumption certainly seemed one which was open to question, or which in any case needed experimental demonstration. At the same time he knew that various engineers in the United States used Mr. Barrus' instrument, and considered it correct.

Measurements of circulating water (page 245) he feared were not likely to come about. He was very sorry that the temperature of the sea and of the discharge had not been taken (page 271); this had been an omission.

In the report he had purposely steered clear of two matters which had been raised in the discussion, namely the combining of indicator diagrams, and the standard of theoretical efficiency. The former had been discussed at meetings of the Institution over and over again; and it was therefore thought by the Committee that there was no occasion for bringing it up once more. As to efficiency, the figure given in the report was the simple ratio between the heat received and the work done, which expressed an indisputable fact. This form of expression everyone could modify for himself as he might wish.

Referring once more to the "Tartar," he wished to point out that at the end of the low-pressure stroke there was actually present as water in the cylinder and jackets together 39·7 per cent. of the whole feed (page 235). Of this, the jackets were answerable for 4 per cent.; so that, as compared with the whole quantity of the feed-water, there was present apparently 35 per cent. as water in the low-pressure cylinder. In the unjacketed low-pressure cylinder of the "Colchester" however, the proportion of water was 47·3 per cent. (page 223). In the very economical engines of the "Meteor" it was about 25 per cent.; so that the quantity in the "Tartar," although large, was by no means incredible, and did not of itself suggest that the whole measured feed-water had in some way failed to get to the engines, although it had arrived at the boilers. All engineers who had ever compared the steam shown by indicator diagrams with measured feed-water would be unfortunately familiar with the fact that 35 per cent. of water at the end of the low-pressure stroke was by no means unheard of.

The desirability had been suggested of knowing what was going on during the trial (page 253), so as to modify arrangements accordingly. But it had to be borne in mind that a trial at sea was by no means so simple an affair as a land trial, and that it was hardly possible under the average conditions of such experiments to find out with accuracy during the trial what the horse-power was, or what the rate of feed consumption; and even if weather and other circumstances allowed it to be known at all accurately within the first few hours of the trial, it would probably be impossible to alter the conditions of working beyond very narrow limits.

As an addition to the present report he should be happy to lay before the Members the particulars of a trial which he had made a short time ago on a Thames tug, the "Eagle"; he was indebted to Mr. G. A. Key for permission to publish these figures. The "Eagle" trial had been made on exactly the same lines as the trials of the Research Committee, although its primary purpose was a different one; and as such a trial was not often made with a small steamer of this kind, he thought the results might be interesting. The engines were ordinary compound screw engines of thoroughly

TABLE 7 (*continued on opposite page*).

Results of Trial of Steam-tug "Eagle."

1	Name of Vessel		Eagle.
2	Date of Trial		6 Nov. 1889
3	Duration of Trial	hours	7·32
4	Type of Engines		compound
5	Cylinder diameter, high-pressure . . .	inches	19
7	„ „ low-pressure	inches	35
8	Stroke, length	inches	22
9	Boilers, number of main boilers . . .		1
10	„ single-ended or double-ended . .		single
11	Furnaces, total number		2
12	Heating surface, total	square feet	900
13	„ „ tubes	square feet	728
14	Grate area	square feet	36
15	Total heating surface to grate area . . .	ratio	25·0
16	Tube surface to grate area	ratio	20·2
17	Grate area to flue area through tubes . . .	ratio	5·58
19	Mean boiler-pressure above atmosphere	lbs. per sq. in.	76·0
20	„ admission „ high-p. cyl. above atm.	lbs. per sq. in.	65·7
21	„ effective „ high-pressure cyl.	lbs. per sq. in.	36·82
23	„ „ „ low-pressure „	lbs. per sq. in.	8·56
24	„ „ „ total referred to low-pressure cyl.	lbs. per sq. in.	19·41
25	„ exhaust „ low-p. cyl. below atm.	lbs. per sq. in.	11·5
26	„ vacuum in condenser below atm.	lbs. per sq. in.	12·7
27	Revolutions per minute, mean	revs.	107·25
28	Piston constant, high-pressure cylinder . .	H.P.	3·38
30	„ „ low-pressure „ . . .	H.P.	11·46
31	Indicated horse-power, high-pressure cylinder .	I.H.P.	124·2
33	„ „ low-pressure „ .	I.H.P.	97·8
34	„ „ mean total . . .	I.H.P.	222·0

(*concluded from opposite page*) TABLE 7.

Results of Trial of Steam-tug "Eagle."

	Name of Vessel	Eagle.
35	Coal burnt per minute . . . . . lbs.	12·35
36	„ „ per hour . . . . . lbs.	741
37	„ „ per sq. ft. of grate area per hour . . lbs.	20·6
38	„ „ per sq. ft. of total heating surface per hour lbs.	0·82
39	„ „ per indicated horse-power per hour . lbs.	3·34
40	Carbon-value of 1 lb. of coal as used . . . lbs.	0·83
41	„ „ equivalent per I.H.P. per hour . . lbs.	2·77
42	Feed-water per minute . . . . . lbs.	81·28
43	„ „ per hour . . . . . lbs.	4,877
44	„ „ per sq. ft. of total heating surface per hour lbs.	5·42
45	„ „ per lb. of coal . . . . lbs.	6·59
46	„ „ per lb. of coal from and at 212° F. lbs.	7·56
47	„ „ per lb. of carbon-value from and at 212° F. lbs.	9·11
48	„ „ per indicated horse-power per hour . lbs.	22·0
49	Calorific value of 1 lb. of coal as used . thermal units	12,000
50	Percentage of line 49 taken up by feed-water . per cent.	60·8
51	„ „ „ „ carried away by furnace gases p. cent.	14·3
52	„ „ „ „ lost by imperfect combustion p. cent.	14·6
53	„ „ „ „ expended in evaporating moisture in coal per cent.	1·0
54	„ „ „ „ unaccounted for . . per cent.	9·3
55	Heat taken up by feed-water per minute . thermal units	90,100
56	„ turned into work per minute . . thermal units	9,490
57	„ taken up by feed-water per I.H.P. per minute Th. U.	405·9
58	Efficiency of boiler (line 50) . . . per cent.	60·8
59	„ of engine (line 56 ÷ line 55) . . per cent.	10·5
60	„ of engine and boiler combined (line 58 × line 59) . per cent.	6·4
61	Mean velocity of steam through water-surface in boilers per minute . feet	6·56
62	Space occupied by boilers per I.H.P. . . cubic feet	3·94

(Professor Kennedy.)

good and substantial design; the cylinders were 19 and 35 inches diameter, with 22 inches stroke. The boiler pressure was 76 lbs. per square inch above the atmosphere, the mean speed 107 revolutions per minute, and the indicated horse-power 222. The consumption of coal was 3·34 lbs. per indicated horse-power per hour. The coal was of very poor quality; and the equivalent of the 3·34 lbs. in actual carbon-value was only 2·77 lbs. The efficiency of the boiler was about 60 per cent. Other details were given in Table 7 (pages 280–281), and the observations were plotted in Plates 101 and 102 in the same manner as for the trials recorded in the report. The indicator diagrams nearest to the mean were shown in Plate 103.

The PRESIDENT said it was now his pleasing duty to move that a cordial vote of thanks be given to Professor Kennedy for the trouble he had taken in preparing the present report; and also to the Committee of which he was Chairman, and to the staffs of observers who had assisted in carrying out the trials.

Mr. D. B. MORISON, being unable to be present at the meeting, wrote as follows respecting the trial of the "Tartar," whose engines had been designed and built by the firm he represented, Messrs. Thomas Richardson and Sons of Hartlepool.

The most important point to be noted is that the "Tartar" was absolutely without cargo during the trial, and that the engines were consequently working under conditions which were not conducive to economy. These engines were designed to do their best work when the ship is fully loaded; and the mean effective pressure referred to the low-pressure cylinder will then be from 27 to 29 lbs. per square inch. On the trial this mean pressure was 19·8 lbs., a difference which cannot be without a great effect on the economy. If 29 lbs. corresponds to an expansion of 10 times, 19·8 will correspond to an expansion of about 15 times. Hence it is evident that the expansion was carried much beyond the extent for which the engines were designed and at which they would be most economical. Although

the engines were running somewhat faster than they would at fully loaded draught, the gain due to this small increase in their speed would not compensate for the above extreme range of expansion. It should also be noted that the engines were working at a still further reduced power for 75 minutes or nearly one eighth of the total time of the trial. Although this is taken into account in calculating the average power and revolutions, it is impossible to take into account the diminution in efficiency, consequent upon the slower speed and lower power. From this cause it is impossible to allow correctly for the period during which the engines were working at reduced power; while to include this period with the rest is to introduce an element of error which must tell greatly against the engines. Under these circumstances it cannot but be regretted that the ship was tried when light, as it is not fair to the engines that erroneous impressions should be formed with regard to their economy; and except for comparison with a further trial of the same ship when loaded, the present trial seems to be of but little value. If however the engines could be again tried with the ship fully loaded and under the conditions for which they were designed, the comparison would be interesting and instructive, and would give a useful indication of the probable economical range of expansion.

Regarding the manner in which the machinery was tried, there can be little doubt that, with a staff of as many as seventeen trained engineers and a chemist experienced in these matters, a reliable trial may be made even on board ship; but there is equally little doubt that such trials are hardly likely to be undertaken by private firms, unless the number of engineers necessary can be largely reduced.

The cubic capacity of the boilers in the "Tartar," found by taking their mean diameter and total length, is 3,910 cubic feet. Taking the "Fusi Yama" and the "Colchester" in the same way, their respective boiler capacities are 1,529 and 4,850 cubic feet. Dividing these figures by the indicated horse-powers, the boiler capacity per indicated horse-power in the three steamers will be respectively 3·60 and 4·28 and 2·45, instead of 4·33 and 4·53 and 2·52 as given in the report (page 224). Had the "Tartar" engines been working at their economical power of say 1,350 I.H.P., the above boiler capacity of 3·60

(Mr. D. B. Morison.)

would have been reduced to 2·90 cubic feet per indicated horse-power. It seems strange that, with the very ample boilers of the "Tartar," priming should be assigned as an explanation of a high boiler efficiency, when it is remembered that with the relatively smaller boilers of the "Meteor" no priming was hinted at, and that the only evidence of priming is the reading from a single thermometer placed in the funnel.

Since the valve-gear for each cylinder can be varied separately, it is easy to make the powers developed in the three cylinders exactly equal, if this is wished.

Mr. MICHAEL LONGRIDGE, as a member of the Committee and unable to attend the meeting, wrote that the results of the "Tartar" trial were altogether anomalous, and the Committee had held more than one meeting before deciding what to say about them. Ultimately the opinion expressed in page 234 was arrived at, that the difference between the measured quantity of feed-water or 19·83 lbs. per I.H.P. per hour, and the maximum probable rate of consumption or 16·5 lbs. per I.H.P. per hour, "must be attributed to priming." It had since occurred to him that it would be better to say "must *for the present* be attributed to priming," so as not to imply that the Committee were satisfied with this explanation. Although the results of the trial were so unexpected and apparently inconsistent, it did not follow that they were incorrect or useless; and it was quite possible that they only required correct interpretation to render them as valuable as any others of the results recorded. The solution of the difficulty he hoped would be found in the mean indicator diagrams which had been plotted at his own request from the entire set of diagrams taken during the whole of each trial; these mean diagrams he considered were the only kind of indicator diagrams that were of use for analysing the working of the engines. As the engines were working against a constant resistance, with constant ratio of expansion, under a nearly constant boiler-pressure, and at a nearly constant speed, the diagrams taken were all of the same general form as the mean diagrams. Separate mean diagrams from the top and bottom of each cylinder would serve no useful purpose, inasmuch as the quantity

of feed-water supplied to each end could not be measured separately.

For the analysis of these mean diagrams, the volumes of the clearances and receivers should first be ascertained. Then from these volumes, and the pressures shown by the mean diagrams, the weight of steam present at each twentieth of the stroke should be calculated, and should be plotted in curves showing the weight of steam present at every point throughout the revolution, and the weight of water present at every point during expansion and compression. Next, the heat contained in the steam and water, and the heat equivalent to the work done either by or upon the steam, should be calculated and plotted; and their sum should be deducted from the total heat received by each cylinder, in order to arrive at the quantity of heat absorbed by the iron. Thirdly, the surfaces of the clearance spaces and receivers should be obtained; and the indicator diagrams should be divided, not into equal parts representing equal distances of piston travel, but into parts representing equal divisions of the circle described by the crank-pin, that is, equal intervals of time; and from these data calculations similar to the former should be made for ascertaining the quantities of heat absorbed per square foot of metallic surface per unit of time. If this analysis were made not only for the "Tartar" but also for the other trials, he believed that many things now obscure would be made clear. The work would be very laborious, but he thought it could be done without much expense; and unless it were carried out, the labour and money already spent upon the trials themselves would have been spent in merely proving that such trials could be conducted on board ship, and that a few particular engines and boilers had worked with certain consumptions of feed-water and coal; while the much more important question, why these particular rates of consumption were required, would be left without even an attempt at a solution.

The need for such an investigation was apparent from the report. In the "Tartar" it was stated (page 235) that the mixture in the high-pressure cylinder after the point of cut-off consisted of 45·2 per cent. of steam and 54·8 per cent. of water. From a similar

(Mr. Michael Longridge.)
calculation made a little later in the stroke, he had found that either the cut-off had not taken place when the pressure was 115·4 lbs. per square inch, or else the valve was leaky. This was shown by the accompanying Table 8, calculated from the mean indicator diagrams on the assumption that the feed-water was 5·13 lbs. per revolution, and that the clearance spaces contained only dry steam at the beginning of the compression. These figures he thought disposed of the suggestion that the excessive consumption of feed-water was due to the light load.

In regard to the gas analysis, he was certainly in favour of continuous aspiration, in preference to the method adopted in these trials. Although the analyses given were doubtless correct as far as they went, he thought they did not go far enough, the consequence being that the results were not concordant. The whole of the residue left after the measurement of the carbonic acid, carbonic oxide, and oxygen, was put down as nitrogen; but if the oxygen in the carbonic acid and in the carbonic oxide and the free oxygen were added together, they amounted to less than corresponded with the nitrogen. This was nearly always the case in what was called technical gas analysis; and the fact of the disagreement opened up the important question of the escape of free hydrogen and unburnt hydro-carbons in the gases. It was often stated that carbonic oxide could not be found when there was considerable excess of air; but his own experience had satisfied him that this was incorrect, and that carbonic oxide could frequently be found when the excess of air was great. Might not free hydrogen and hydro-carbons pass off unburnt in the same way? He understood Mr. Wilson's opinion was that hydrogen burnt so easily that it was not possible for it to escape from the furnace if there was oxygen to burn it. On the other hand the experiments of Mr. Scheurer-Kestner ("Recherches sur la combustion de la houille," Mulhouse 1868) showed that about 20 per cent. of the hydrogen in the coal passed off unconsumed, whether the supply of air was large or small. Dr. Bailey of Owen's College, Manchester, had come to a similar conclusion with regard to hydro-carbons whenever the supply of air fell below or exceeded certain limits, and whenever the firing was irregular (Journal of the

TABLE 8.—*Weight of Steam and Water in Cylinders of S.S. "Tartar."*

Cylinder.	Weight in pounds, and Percentage, at successive stages of the stroke.	Steam. Lbs.	Steam. Per cent.	Water. Lbs.	Water. Per cent.	Total. Lbs.
High-pressure.	Steam left from previous stroke, at beginning of compression	...	...	...	...	0·58
	Supplied during admission	...	...	...	...	2·56
	Present at 50 per cent. of stroke	2·070	66·0	1·070	34·0	3·14
	„ „ 55 „ „	2·080	66·3	1·060	33·7	3·14
	„ „ 60 „ „	2·080	66·3	1·060	33·7	3·14
	„ „ 65 „ „	2·100	66·9	1·040	33·1	3·14
	„ „ 70 „ „	2·110	67·3	1·030	32·7	3·14
	„ „ 75 „ „	2·120	67·6	1·020	32·4	3·14
	„ „ 80 „ „	2·180	69·6	0·960	30·4	3·14
Intermediate.	Steam left from previous stroke, at beginning of compression	...	...	...	...	0·40
	Supplied during admission	...	...	...	...	2·56
	Present at 65 per cent. of stroke	1·936	65·4	1·024	34·6	2·96
	„ „ 70 „ „	1·902	64·3	1·058	35·7	2·96
	„ „ 75 „ „	1·900	64·2	1·060	35·8	2·96
	„ „ 80 „ „	1·871	63·5	1·089	36·5	2·96
	„ „ 85 „ „	1·836	62·0	1·124	38·0	2·96
Low-pressure.	Steam left from previous stroke, at beginning of compression	...	...	...	...	0·24
	Supplied during admission	...	...	...	...	2·56
	Present at 55 per cent. of stroke	1·675	59·8	1·125	40·2	2·80
	„ „ 60 „ „	1·707	61·0	1·093	39·0	2·80
	„ „ 65 „ „	1·724	61·6	1·076	38·4	2·80
	„ „ 70 „ „	1·765	63·0	1·035	37·0	2·80
	„ „ 75 „ „	1·765	63·0	1·035	37·0	2·80
	„ „ 80 „ „	1·814	64·8	0·986	35·2	2·80
	„ „ 85 „ „	1·799	64·2	1·001	35·8	2·80

(Mr. Michael Longridge.)

Society of Chemical Industry, 31 May 1889). In future trials therefore he trusted that complete analyses both of coals and gases might be made, so as to be considered in conjunction with the forms and dimensions of the furnaces; for he imagined the quantities of combustible gases passing off depended a good deal on the way in which the air was admitted, and on the way in which the flame was brought into contact with the boiler plates.

There was at present a want of a reliable and workable thermometer for high temperatures, and also of an instrument for measuring the percentage of water in steam. When furnace temperatures and wetness of steam could be accurately measured, a great advance in the comprehension of both boilers and engines would follow. Until they could be measured, the laws of transmission of heat through boiler plates and into cylinder metal would probably remain unknown.

Professor KENNEDY wrote that, in reference to Mr. Morison's letter (page 282), he had nothing to add to the remarks he had already made (page 277) about the lightness of the "Tartar" during her trial, and about the priming. He believed Mr. Morison was perfectly right in saying that if the engines had exerted more power, as they certainly did under the conditions of working for which they were designed, they would have been more economical. He pointed out however that, if his estimate of the steam actually used by the engines (page 234) was correct, they were already working with very considerable economy; and whatever blame was due was to be attached rather to the boilers.

Mr. Longridge's remarks in regard to furnace-gas analyses (page 286) somewhat surprised him. He believed it was perfectly impossible for free hydrogen to pass away unburnt. The hydrocarbons which no doubt would be formed to a greater or less extent, and whose determination was, as Mr. Longridge said, undoubtedly important, would, he feared, elude gaseous analysis for the simple reason that they would condense either in the chimney or in the sample bottle. No signs of any were found in the latter, in any of the cases under discussion. He also doubted very much whether any

thoroughly good analyses had ever shown carbonic oxide to be present in furnace gases with great excess of air, although no doubt this was possible under conceivable conditions. Of course the analysis of furnace gases with anything approaching to accuracy was not an extremely simple chemical operation; and many results which had been published in perfect good faith must no doubt be taken as only rough approximations. The apparent discrepancy pointed out by Mr. Longridge in the quantity of nitrogen present was mainly accounted for by the fact that a portion of the oxygen would pass away combined with hydrogen as steam, and that this oxygen was not included at all in the analysis, which like all furnace-gas analyses was made of the *dry* gas. If Mr. Longridge would take this quantity into account, making any reasonable assumption as to how much hydrogen had been burnt completely, he would find that the remaining discrepancy was well within the limits of error of the instruments and methods used. If Mr. Longridge could bring forward any way in which more complete and also more trustworthy analyses could be made of either coal or gas—for he seemed to think that both sets of analyses were incomplete—he would do all in his power to secure that such analyses should be made. At present it appeared to him that the suggested incompleteness was due to mistake on Mr. Longridge's part, and not on his own. Certainly if the furnace gas from a hydrogenous coal gave an average analysis of only 79 per cent. of nitrogen, it would be presumptive evidence that the analysis was wrong, and not right.

The thermometer which he had employed was an ordinary mercury thermometer containing compressed nitrogen over the mercury, which he considered was an instrument quite reliable and workable (page 288) for temperatures up to about 420° centigrade or 788° Fahr.; this was quite high enough for all ordinary chimney-gases. He agreed that it was most important that some instrument should be devised for measuring in a trustworthy manner the wetness of steam (page 288).

In conclusion, while he had every wish to make these trials as complete as possible in every respect, yet it should be borne in mind

(Professor Kennedy.)

that the functions of the Research Committee were precisely those which Mr. Longridge thought so insufficient (page 285). The Committee had been appointed under the following resolution of the Council (17 Dec. 1886):—"That a Research Committee on Marine-Engine Trials be appointed, with instructions to endeavour (1) to draw up a standard system for conducting Marine-Engine Trials, and (2) to arrange for the carrying out of such trials in accordance with this system." In view of the strenuous denials expressed beforehand of the possibility or practicability of such trials, he considered it was no mean or unworthy result even simply to have shown that they were possible and practicable.

MEMOIRS.

William Jeremiah Hall, the eldest son of Mr. Ambrose Hall, J.P., Limerick, was born on 17th July 1851. He studied engineering in Queen's College, Cork, and in 1873 received the degree of Bachelor in Civil Engineering at the Queen's University in Ireland. During his apprenticeship to Mr. John Long, Harbour Engineer, Limerick, he assisted in the building of the graving dock for the accommodation of large sea-going vessels, and other works in connection with the port and harbour of Limerick. Afterwards he became assistant to Mr. William Barrington, under whom he was engaged in surveying for contract plans about 10 miles of the Limerick and Kerry Railway, and also on the Mulcair drainage and other general works. On Mr. Long's retirement in 1877 he was elected Limerick Harbour Engineer, which position he held till his death. Amongst the works on which he was engaged were included the deepening of the entrance to the floating dock and the erection of new steel dock gates, and improvements in the buoying and lighting of the river Shannon. By order of the harbour commissioners he prepared designs, plans and estimates for the following projected works:—extension of the floating dock and construction of new entrance; construction of central pier for floating dock; removal of Cock rock and Waller's bank in the Shannon; deepening the Shannon from Limerick to Grass Island; construction of Coonagh Canal; and erection of pier at Foynes harbour. Whilst superintending the rebuilding of the north wall of the floating dock he was attacked by typhoid fever, which caused his death on 21st May 1890, in the thirty-ninth year of his age. He published a directory of Limerick harbour, and contributed two papers to the Institution of Civil Engineers, on the new steel dock gates of Limerick floating dock (Proceedings 1889, vol. xcvii, page 335), and on rebuilding the wall of Limerick floating dock. He became a Member of this Institution in 1886.

ROBERT WEBB PEARCE was born in Macclesfield, Cheshire, on 11th November 1831, and was educated at the grammar school in that town. Removing to Birmingham, he became apprenticed to Messrs. Brown Marshalls and Co., at their old works then in New Canal Street, and afterwards at their new Britannia Carriage Works, Saltley. Passing through the shops he became confidential assistant and chief of the drawing office. In 1855 he was offered and accepted the post of carriage and wagon superintendent of the East Indian Railway, and left England in December 1855; but finding his position not what he expected, he would have left the railway and started wagon-building works in India. He was persuaded however to remain, and afterwards had independent charge of the carriage and wagon department from Howrah to Delhi and Jubbulpore, about 1,500 miles of line. The large works at Howrah were designed and built under his superintendence, employing at the busiest time from three to four thousand native workmen, all trained under him. The whole of the East Indian Railway stock has been built or erected at the Howrah works, together with a great portion of the stock in use by the metre-gauge railways. His designs have been copied throughout India, and he was the first to introduce iron instead of wood for the panels and framing of carriages and wagons; and the results have fully proved he was right. He was also the first to recognise the value of oil as a lubricant for railway vehicles, instead of grease; and his design of an axle-box for oil and cotton waste has become almost universally adopted in India. He nearly doubled the carrying power of the old wagon stock, by increasing the size of axle and journal; and, had he lived, would shortly have completed his design of 18 feet by 9 feet iron covered goods wagon, weighing 7 tons and carrying 15 tons, a gross load of 22 tons on two axles with $4\frac{1}{2}$ inch journals; paying load more than 2 to 1. The improvements he introduced into railway carriages and wagons were so numerous and so important that he has been called the father of carriage and wagon building in India, and is looked upon in this light by the natives. His long residence in the tropical climate of Bengal, and his disinclination to take leave of absence during thirteen years with scarcely a day's holiday, and his constant application to work, eventually told on a fine constitution.

A few years ago he was attacked with malarious fever, from which he never quite recovered; and in April 1888 he took furlough to England, but too late to shake off the effects of climate; and he died at West Kensington, London, on 26th July 1889, at the age of nearly fifty-eight. He became a Member of this Institution in 1867.

David Rollo was born in Glasgow on 25th November 1820. He commenced his business life there as a draughtsman in the marine engine works of Messrs. J. and G. Thompson, Clydebank, of which he subsequently became manager. He remained in Glasgow until 1854, when he went to Liverpool to take the post of manager to Messrs. James Jack and Co., whom he afterwards joined as partner in the firm of Messrs. Jack, Rollo and Co. That was a period of great importance in marine engineering, for the transition from wooden to iron ships and from paddle wheels to screw propellers was then in progress; and his firm took a leading position in the development of improvements. In 1877 he retired from this partnership, and founded with his two sons the Fulton Engine Works, Liverpool, under the firm of Messrs. David Rollo and Sons. Many of the fine steamers now afloat have been engined under his direction, and are examples of his good work. He died on 28th May 1890, at the age of sixty-nine. He became a Member of this Institution in 1871.

Charles Wells was born at Moxley, near Bilston, on 15th November 1836, but for many years had resided at Wolverhampton. In 1876 he succeeded with his brother to the business previously carried on by their father of iron and steel manufacture at Moxley, where they made large sheets, plates, and bars of iron and steel. He was a thoroughly practical man, and had an extensive knowledge of the iron trade as a manufacturer. He died on 1st May 1890, at the age of fifty-three; and for some years had been a county magistrate for Staffordshire. He became a Member of this Institution in 1862.

Thomas Wilson was born on 26th October 1843 at Inverneil, Ardrishaig, Argyleshire. He received his early training with

Messrs. Denny and Co., Dumbarton; and on the completion of his service with that firm he entered the employment of Messrs. John Elder and Co., Govan, and also spent a considerable time with Messrs. J. and S. Thompson, Dalmuir. He thus acquired a thorough knowledge not only of the marine engine, but also of shipbuilding and repairing. He then went to sea as an engineer, and was afterwards employed by Messrs. Jardine Mathieson and Co., Shanghai, China, where he remained for several years. On his return to England he became connected with the works of Messrs. Amos and Smith, and the Wilson line of steamers, Hull. In 1880 he was appointed, by the committee of Lloyd's Register of British and Foreign Shipping, to the position of engineer surveyor for the Tyne district. He afterwards took the management of the engine department of the Wallsend Slipway and Engineering Co., Newcastle, with whom he remained until 1887, when he received the appointment of superintendent engineer to the General Steam Navigation Co., London, with the entire management of their repairing works at Deptford. His death occurred on 15th January 1890 at the age of forty-six, from an attack of the influenza epidemic. He became a Member of this Institution in 1884.

1825. Stockton and Darlington Railway.

By George Stephenson.

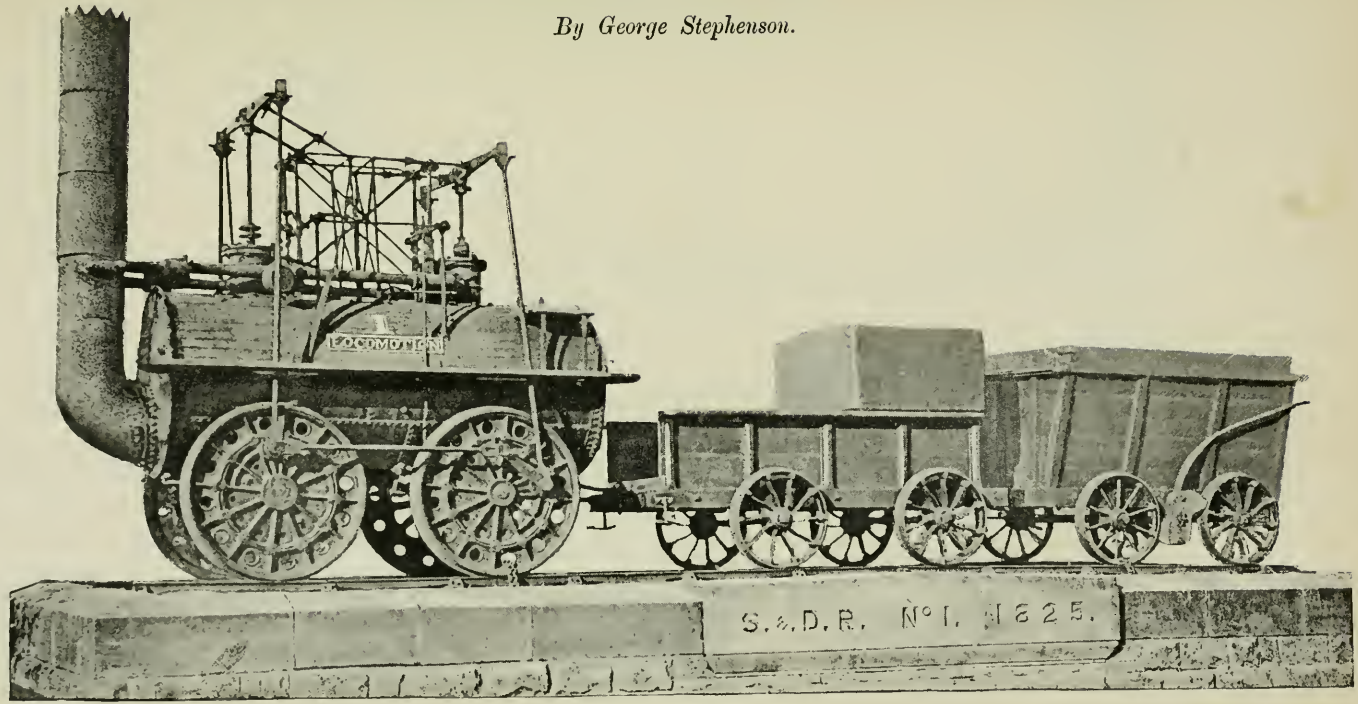


Plate 42.

1827. STOCKTON AND DARLINGTON RAILWAY.

By Timothy Hackworth.

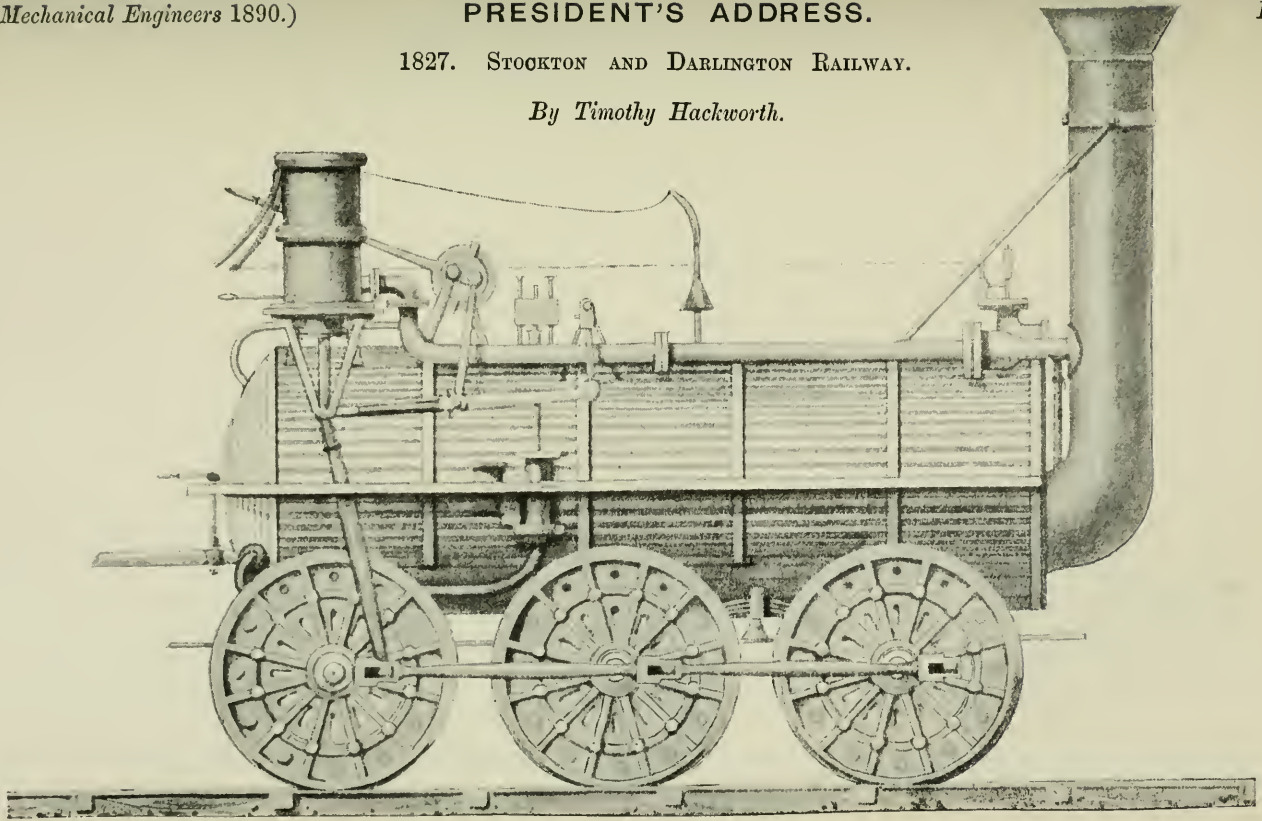


Plate 43.

1829. LIVERPOOL AND MANCHESTER RAILWAY.

By George Stephenson.

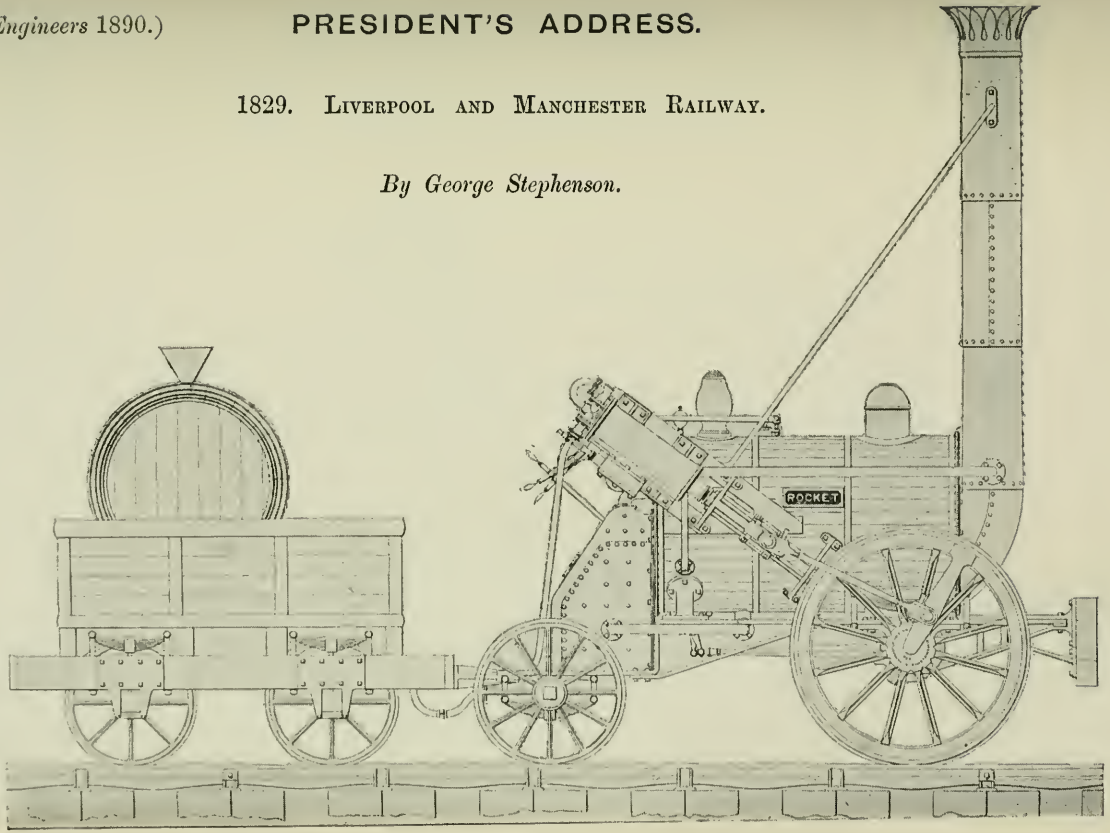


Plate 44.

1832. STOCKTON AND DARLINGTON RAILWAY.

By R. and W. Hawthorn and others.

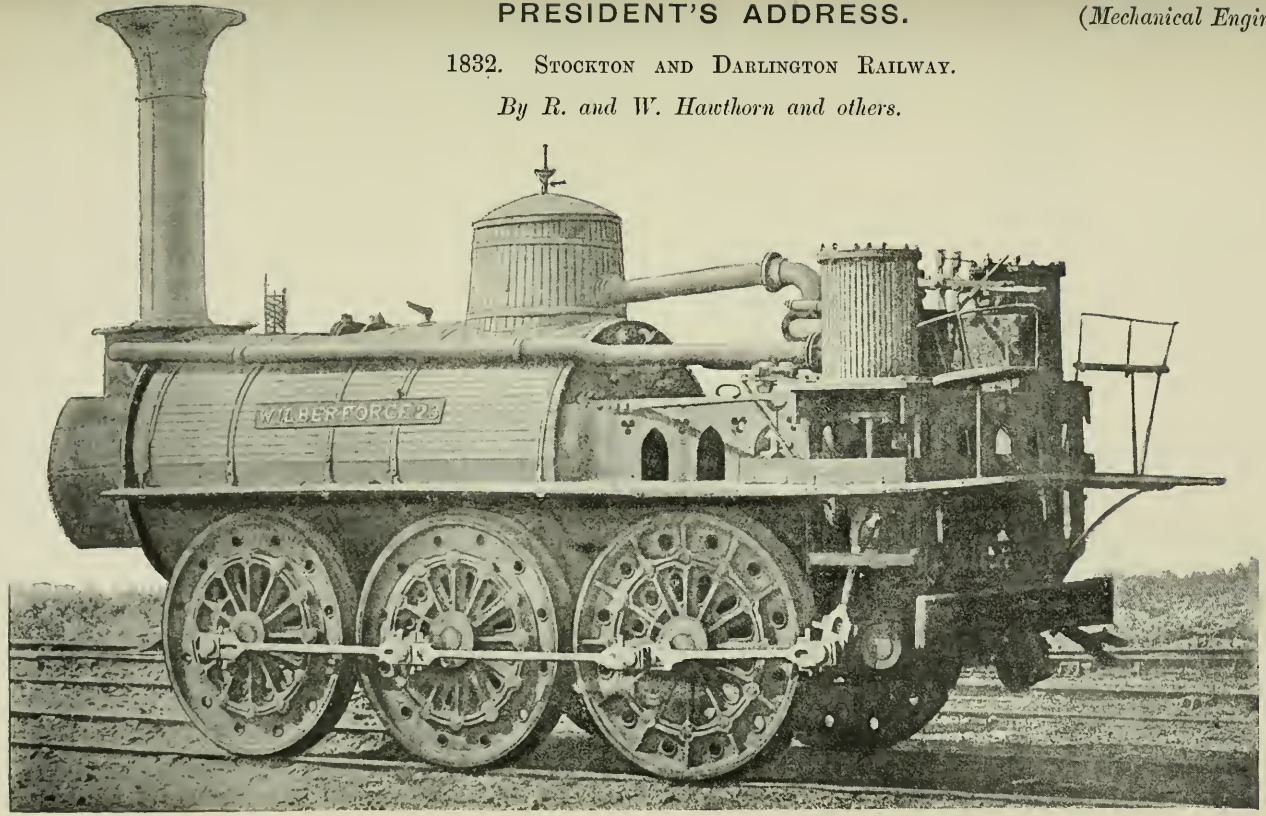


Plate 45.

1833. DUNDEE AND NEWTYLE RAILWAY.

By Carmichael, Dundee.

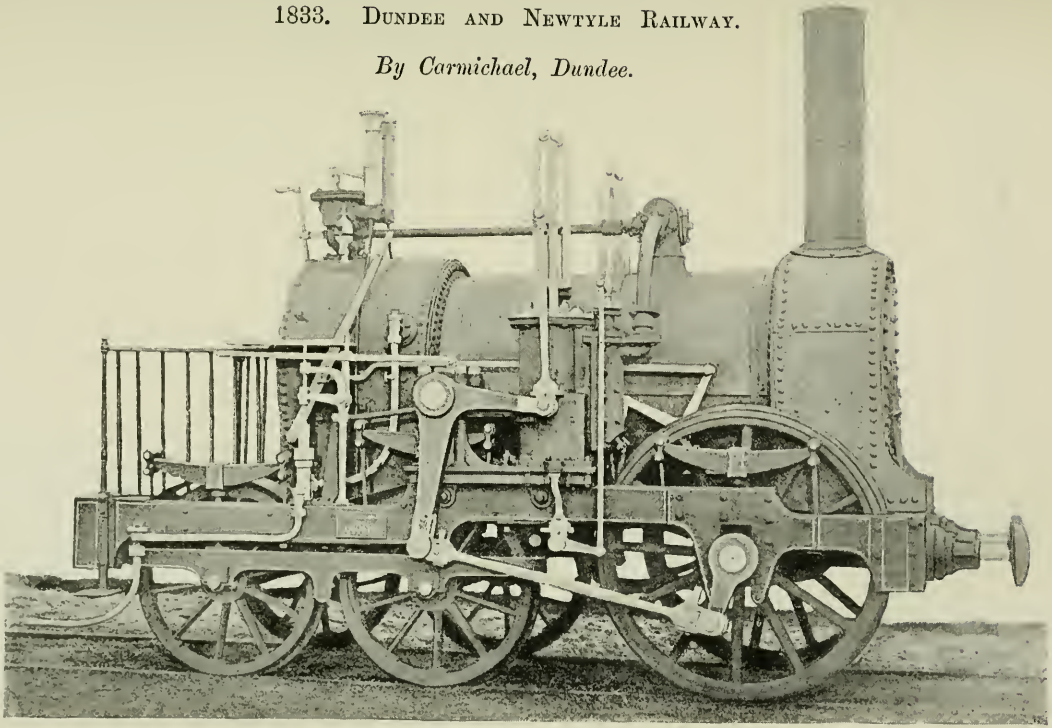


Plate 46.

1834. Dublin and Kingstown Railway.

By Sharp Roberts and Co.

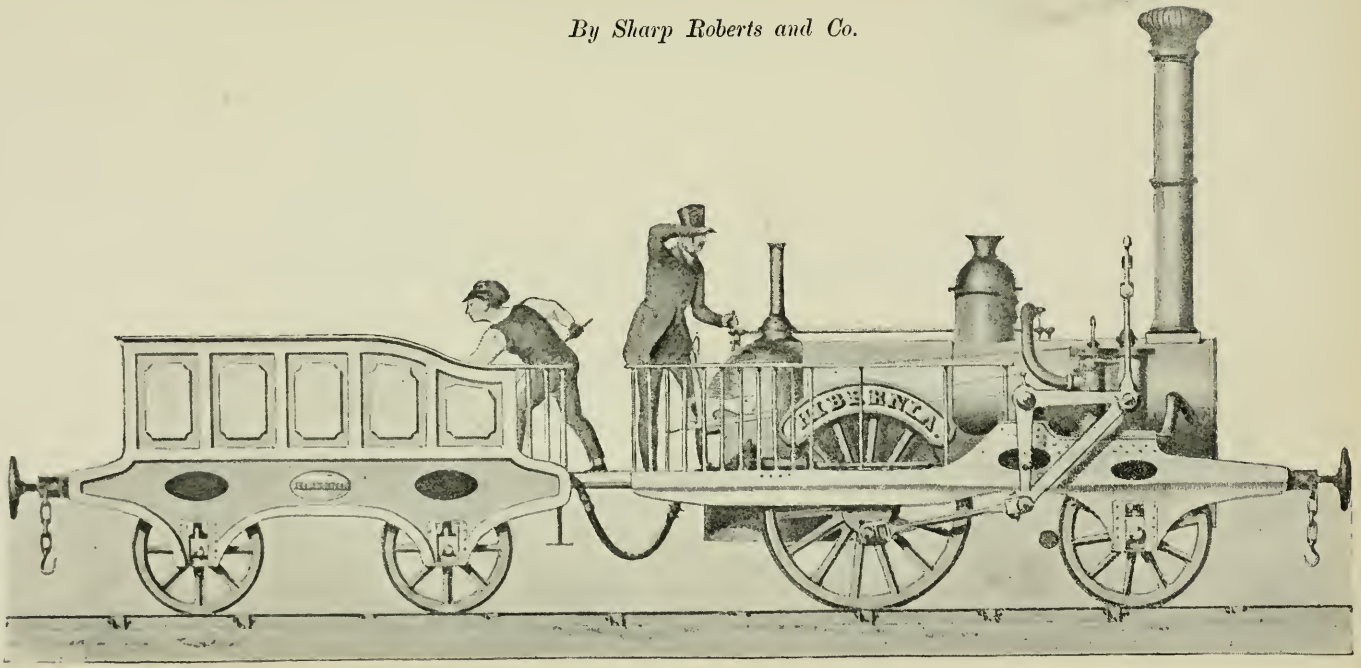


Plate 47.

1834. LIVERPOOL AND MANCHESTER,

AND DUBLIN AND KINGSTOWN RAILWAYS.

By Forrester, Liverpool.

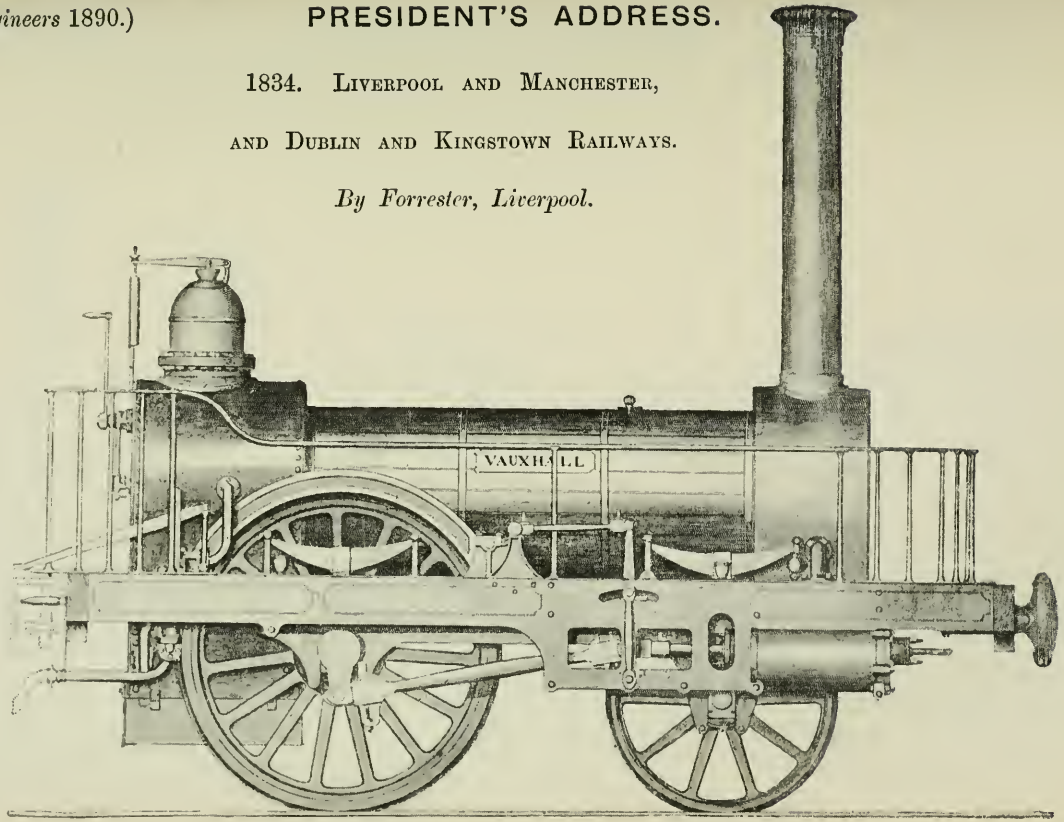


Plate 48.

1837. Stockton and Darlington Railway.

By R. and W. Hawthorn.

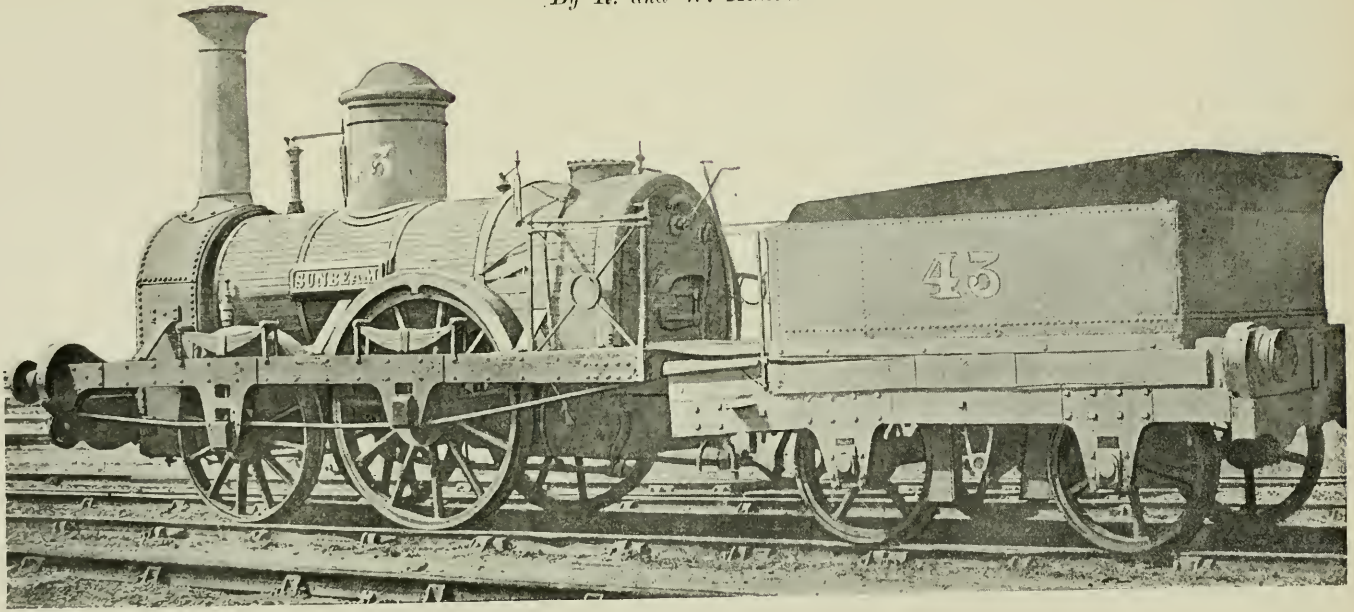


Plate 49.

1838. Stockton and Darlington Railway.

By Timothy Hackworth.

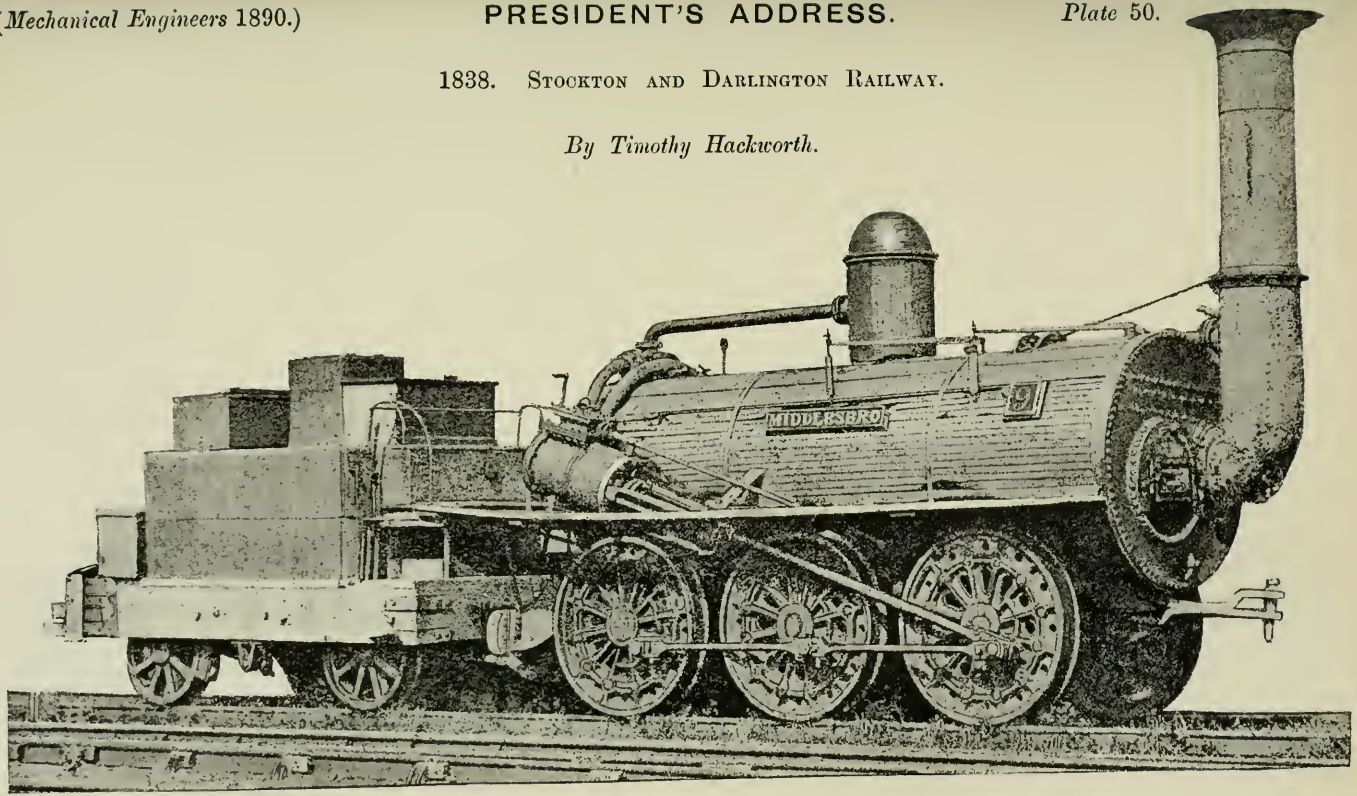


Plate 50.

1842. Stockton and Darlington Railway.

By Timothy Hackworth.

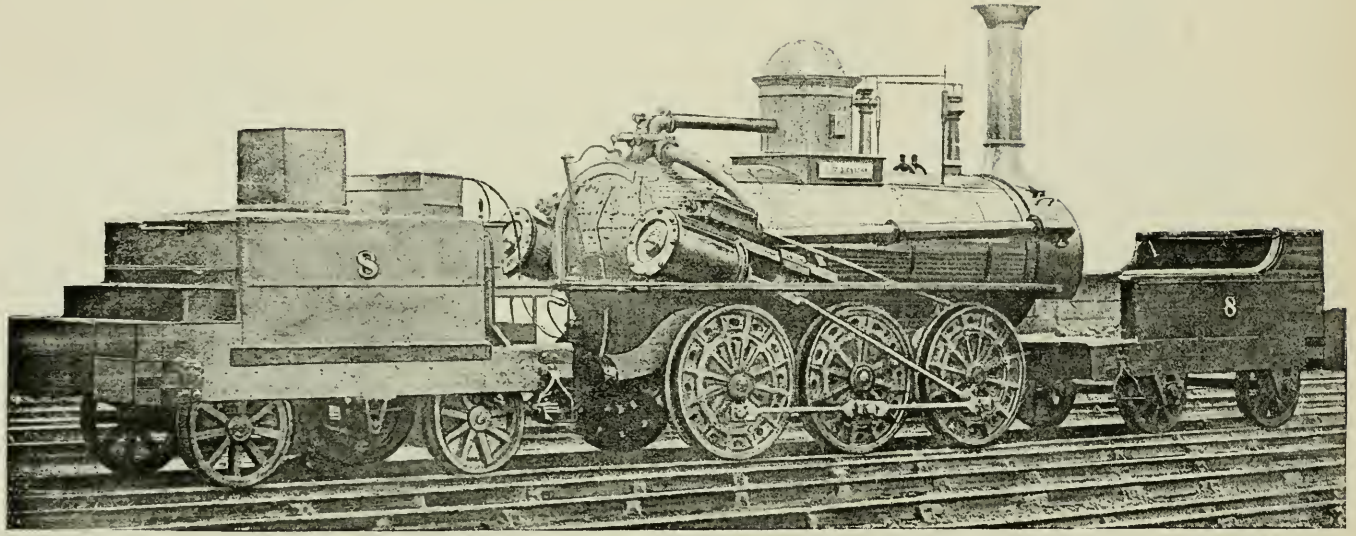


Plate 51.

About 1844. Llanelly Dock and Railway.

By Fossick and Hackworth.

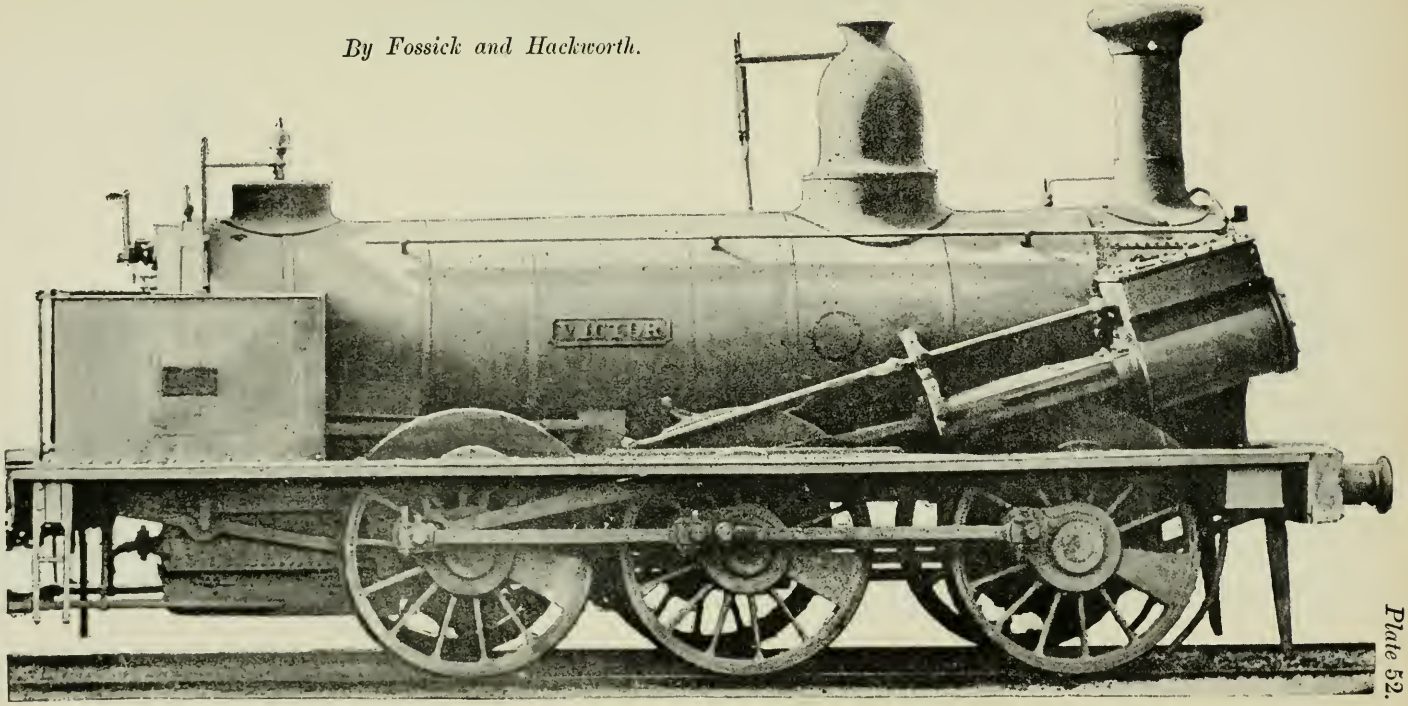


Plate 52.

1846. Stockton and Darlington Railway.

By William Bouch and D. Dale.

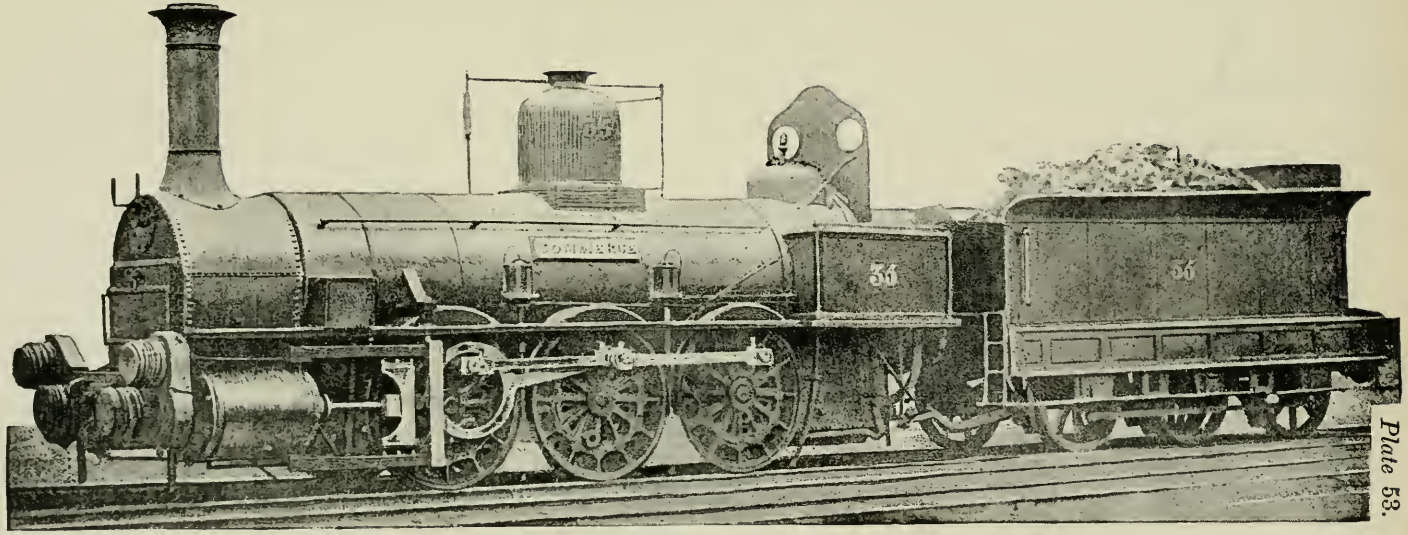


Plate 53.

1846. Northern of France and Western of France,

and London and North Western and other English Railways.

By Thomas Russell Crampton.

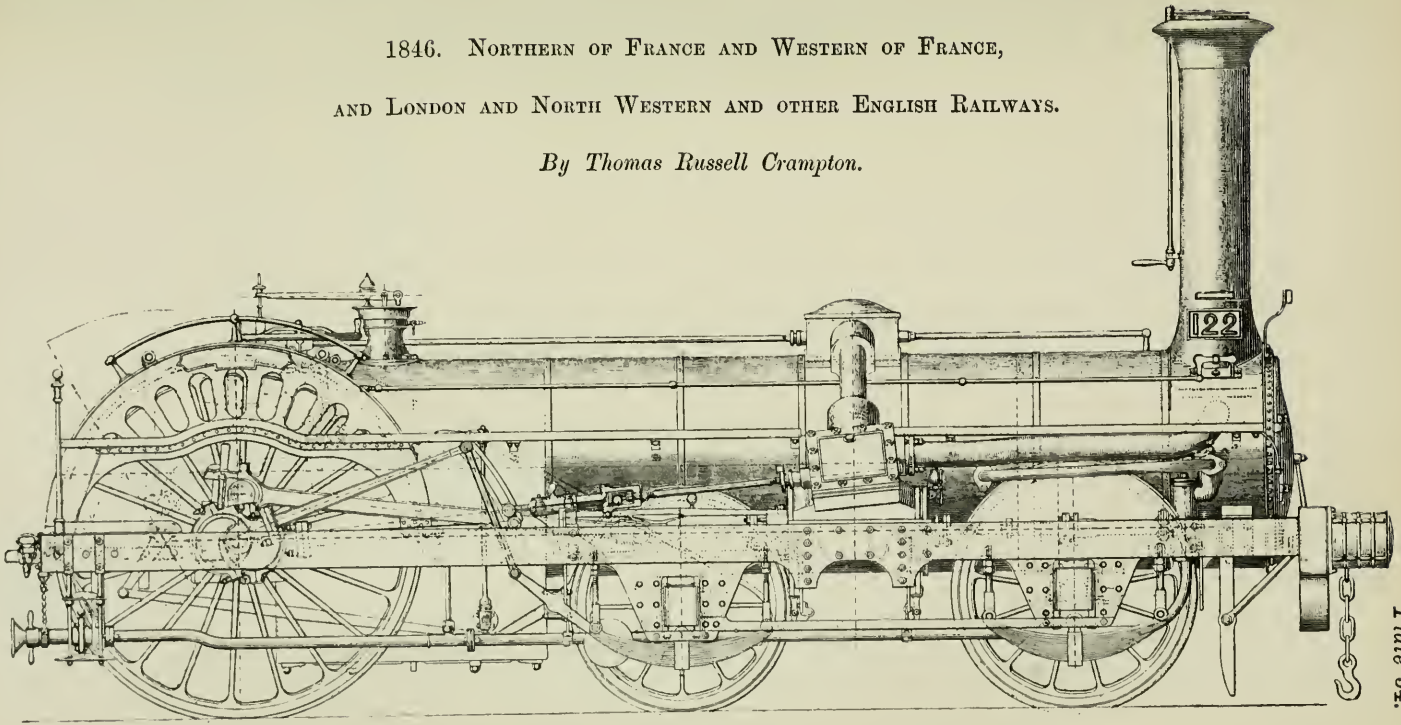


Plate 54.

1846. Manchester Sheffield and Lincolnshire Railway, etc.

By Sharp Stewart and Co.

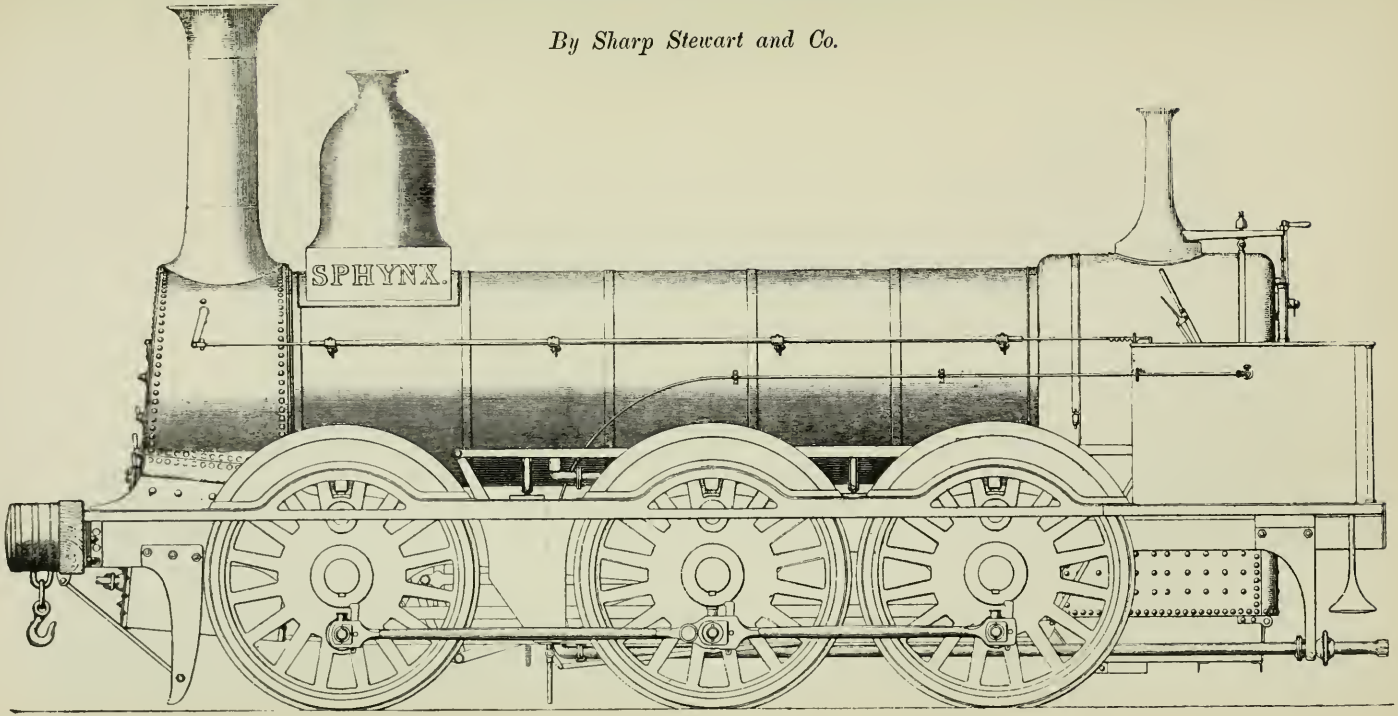


Plate 55.

1846. GREAT WESTERN RAILWAY.

By Daniel Gooch.

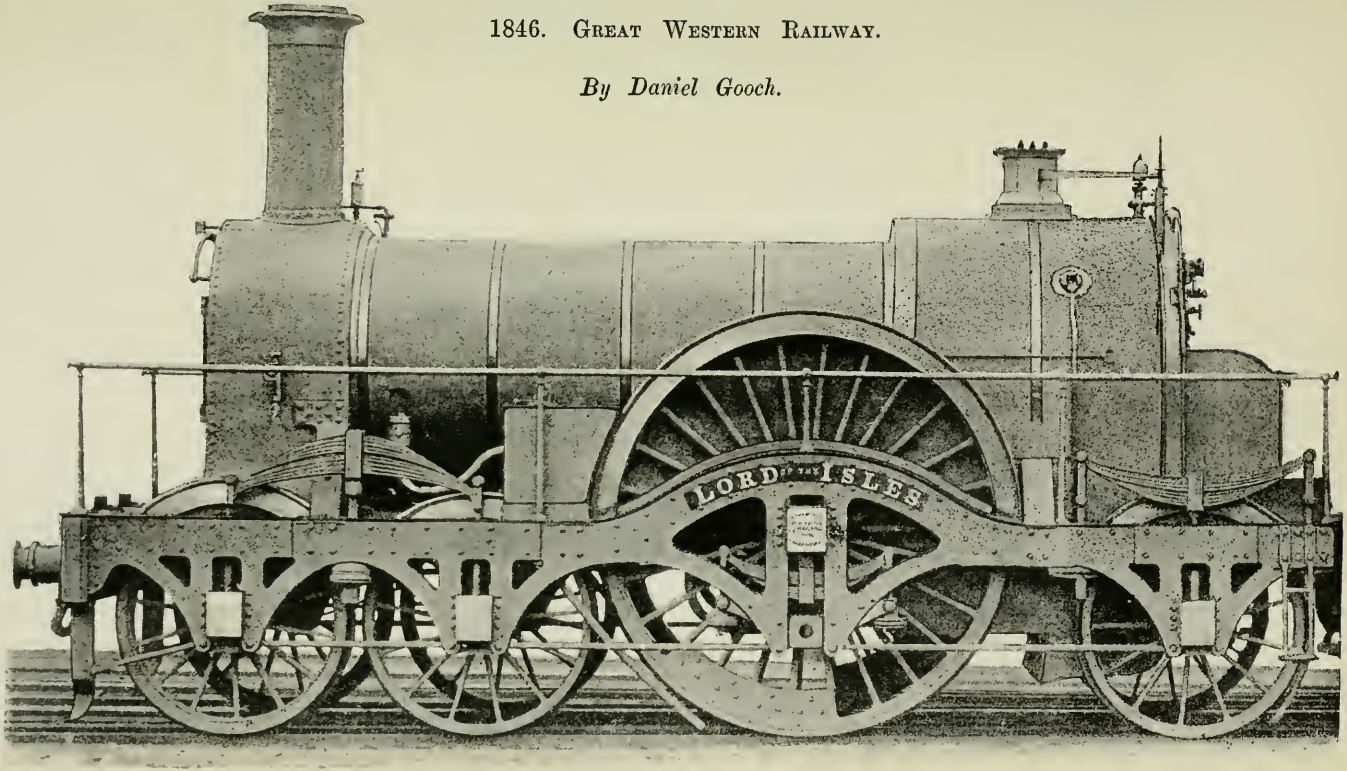


Plate 56.

1847. GREAT WESTERN AND SOUTH DEVON RAILWAYS.

By Daniel Gooch.

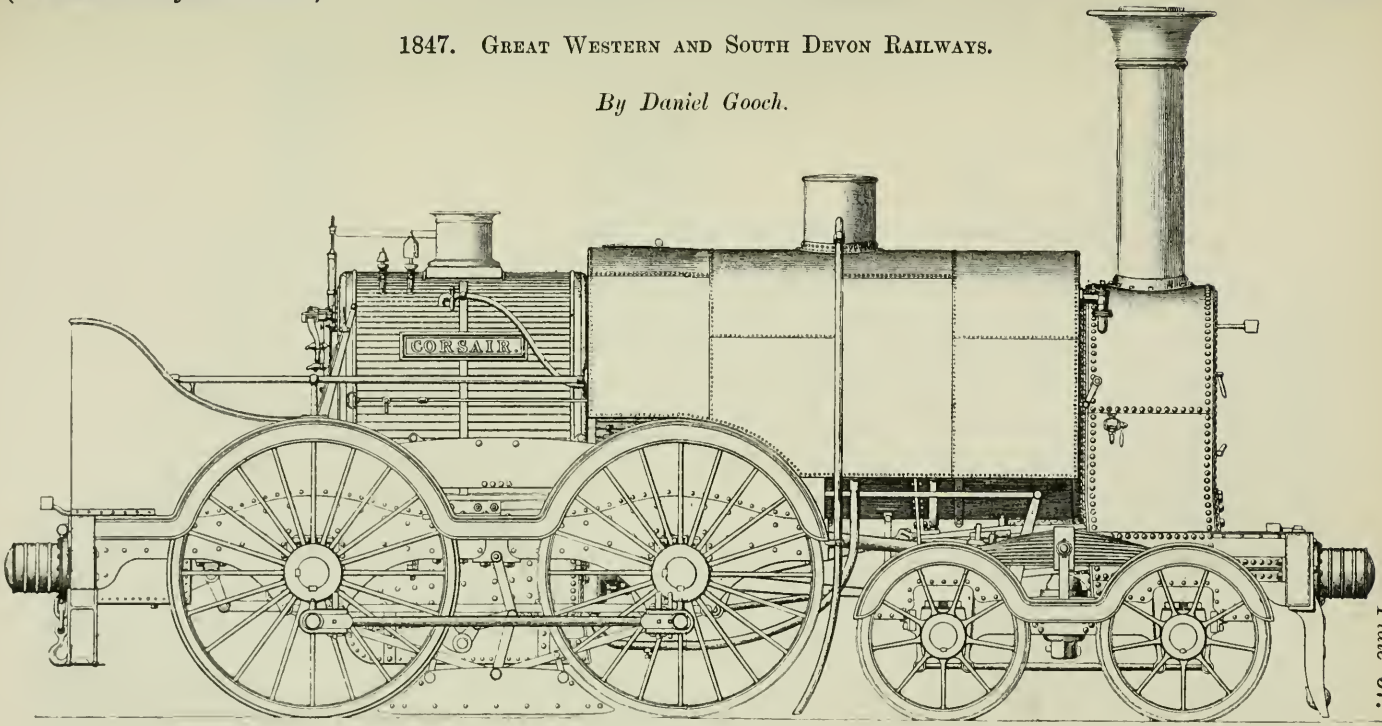


Plate 57.

1847. London and North Western Railway.

By Francis Trevithick; altered by John Ramsbottom as here shown.

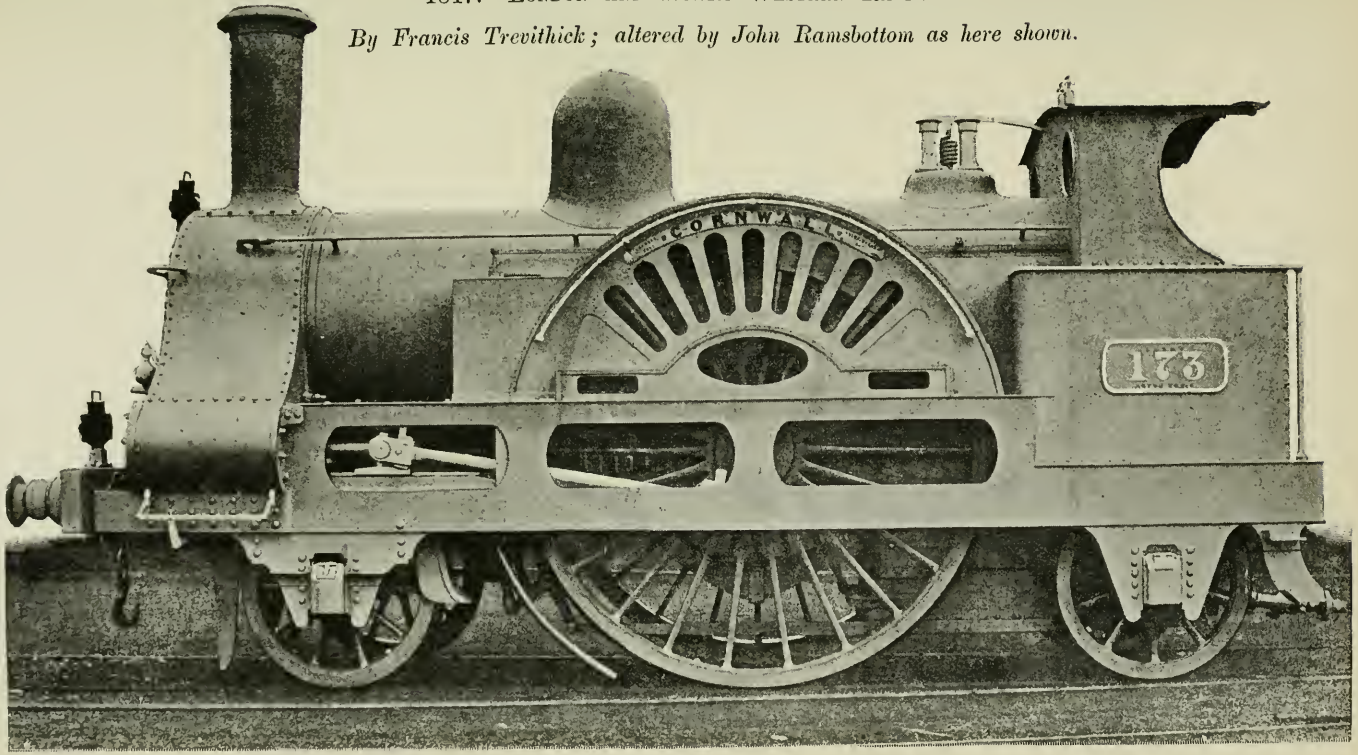


Plate 58.

1849. Shrewsbury and Birmingham Railway.

By William Fairbairn.

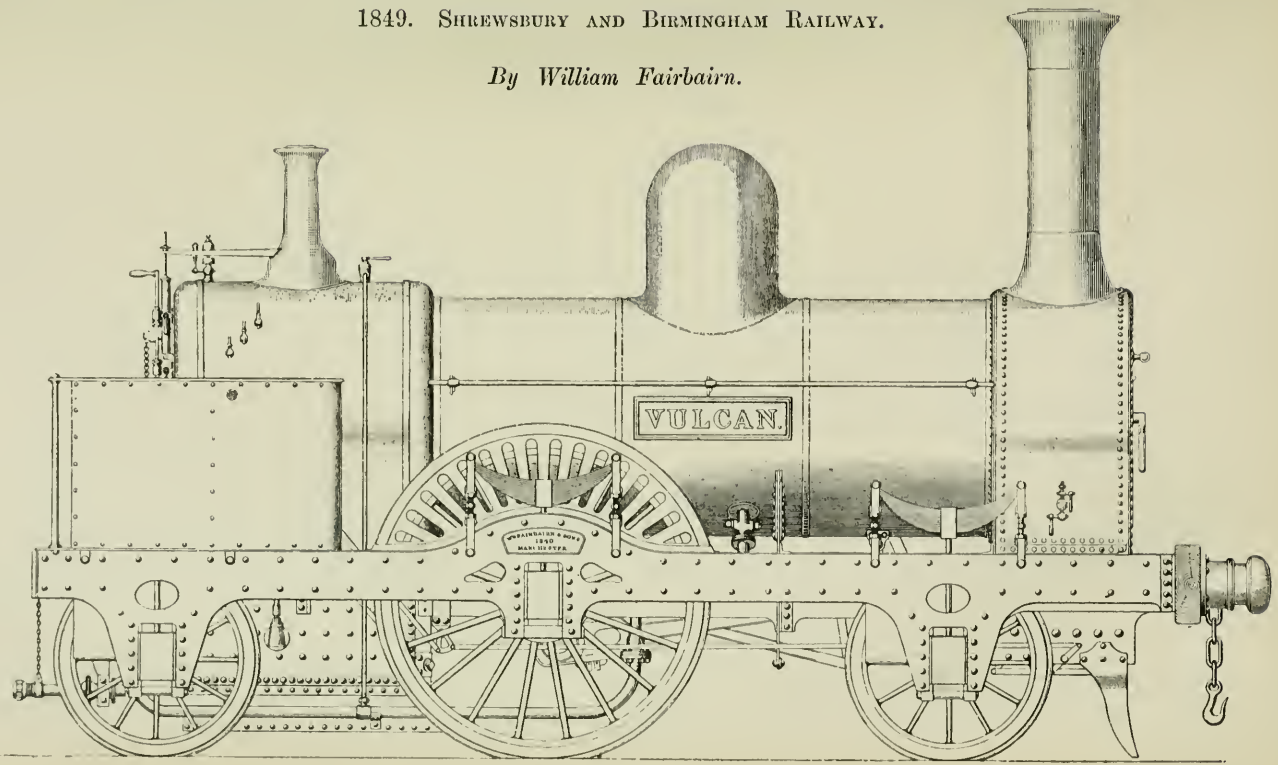


Plate 59.

1849. MIDLAND, NORTH EASTERN, AND OTHER RAILWAYS.

By James Fenton, at E. B. Wilson and Co., Leeds.

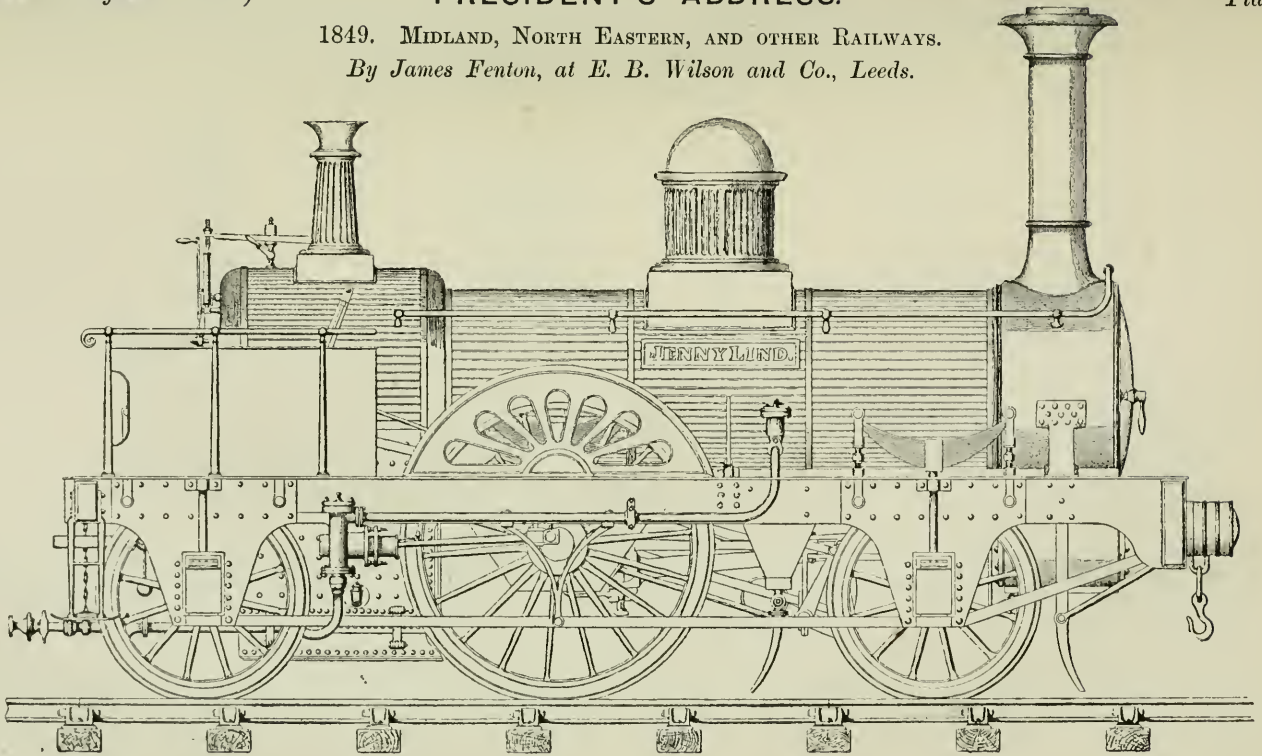


Plate 60.

1851. Bloomer Class. London and North Western Railway.

By James E. McConnell.

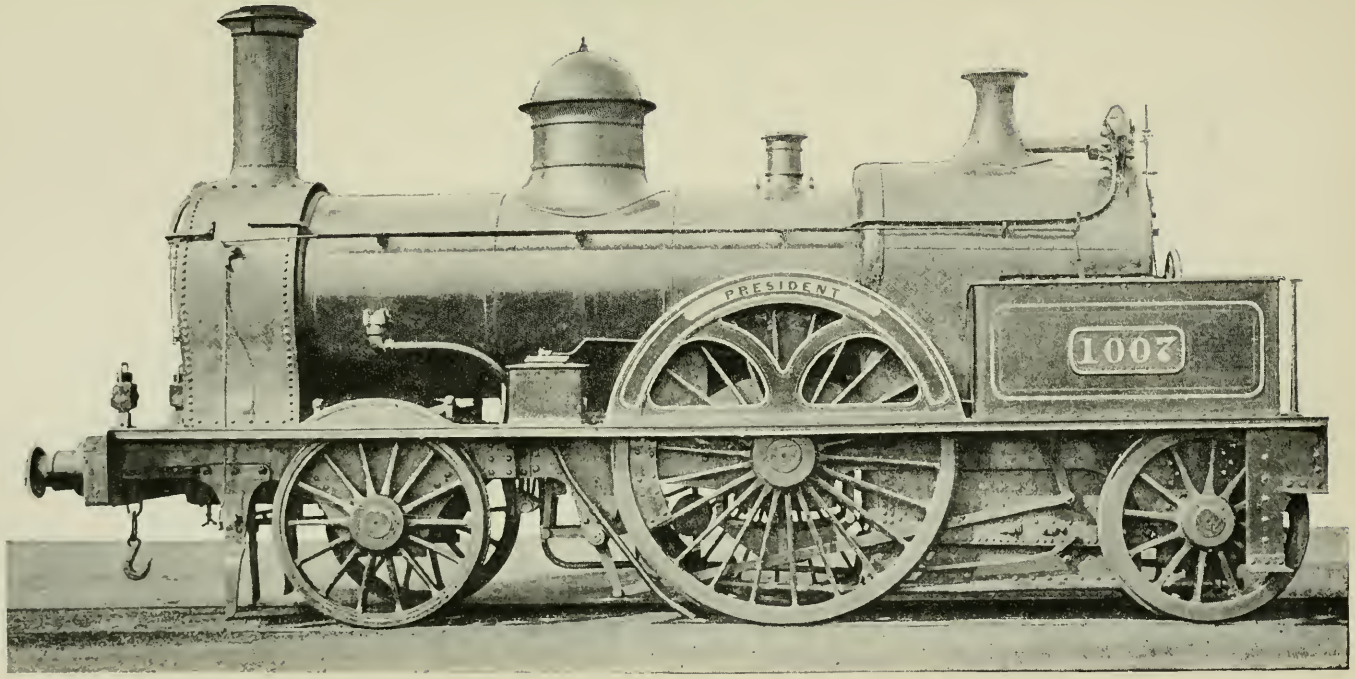


Plate 61.

1852. North Stafford Railway.

By Kitson Thompson and Hewitson.

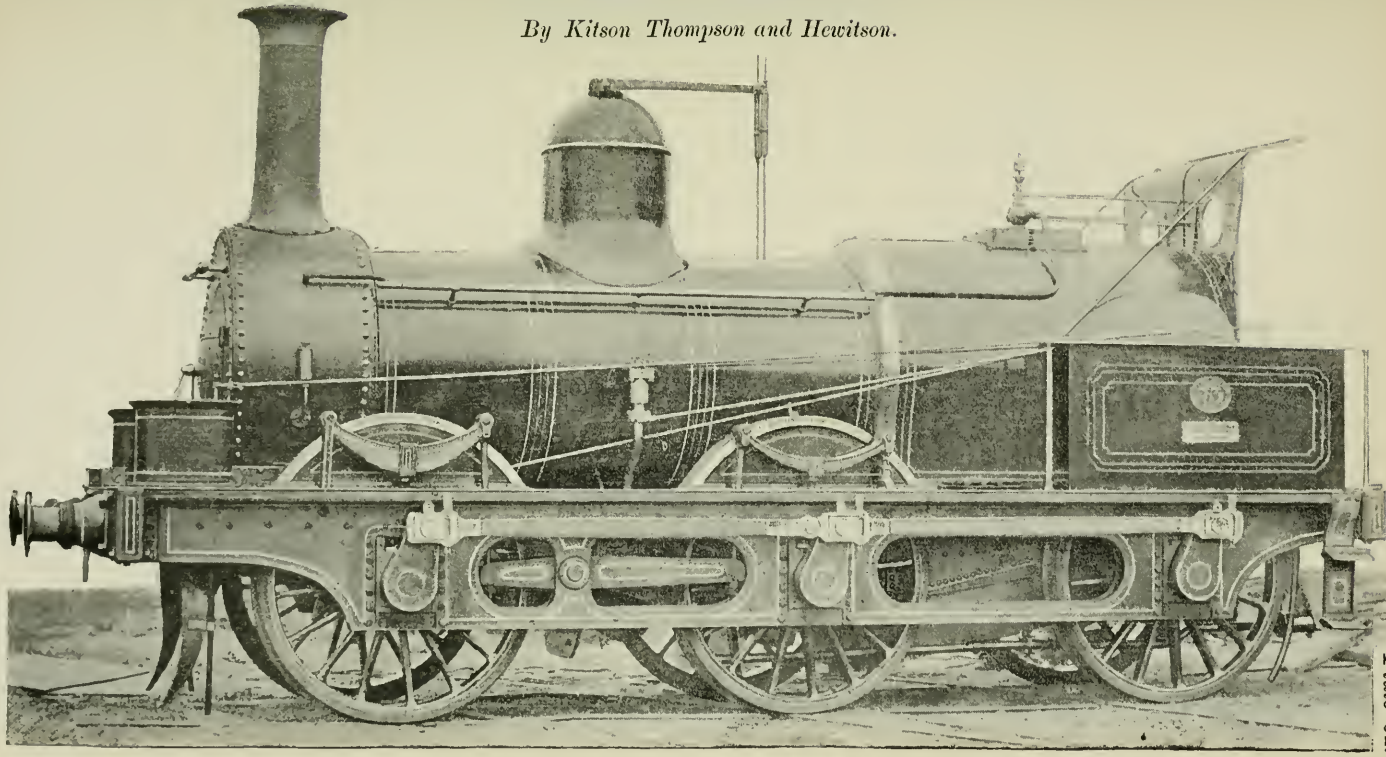


Plate 62.

1852. Caledonian, Scottish Central, and other Railways.

By Alexander Allan.

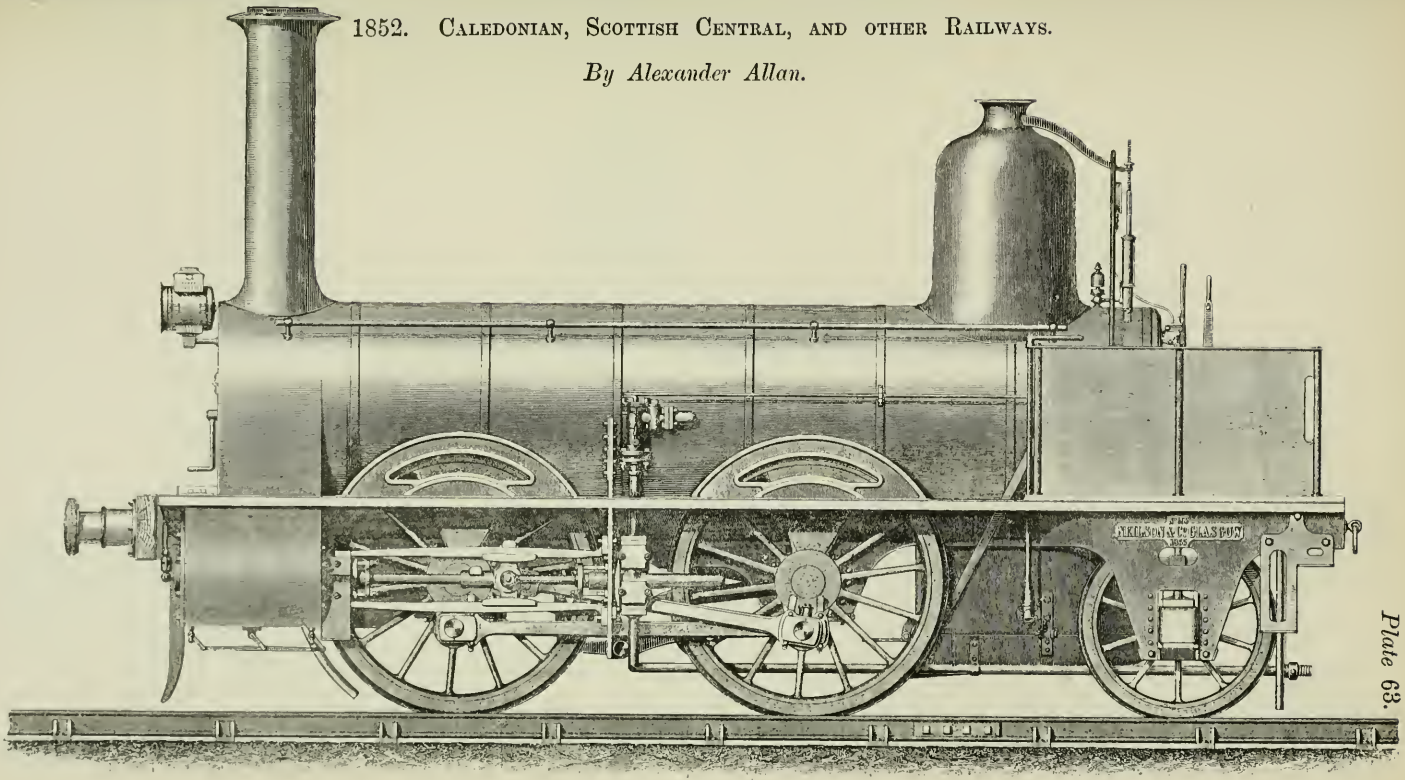


Plate 63.

1857. Midland Railway. *By Matthew Kirtley.*

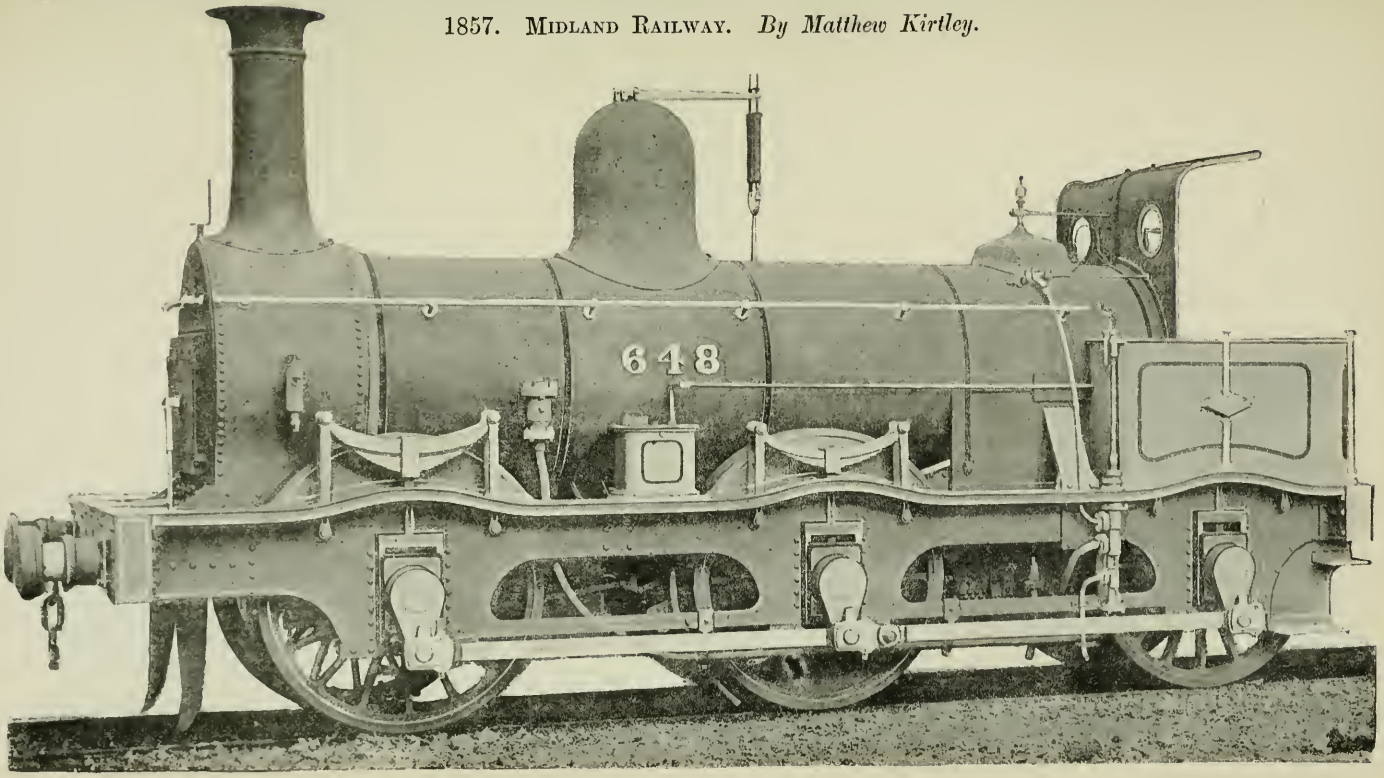


Plate 64.

1858. TAFF VALE RAILWAY. *By Joseph Tomlinson.*

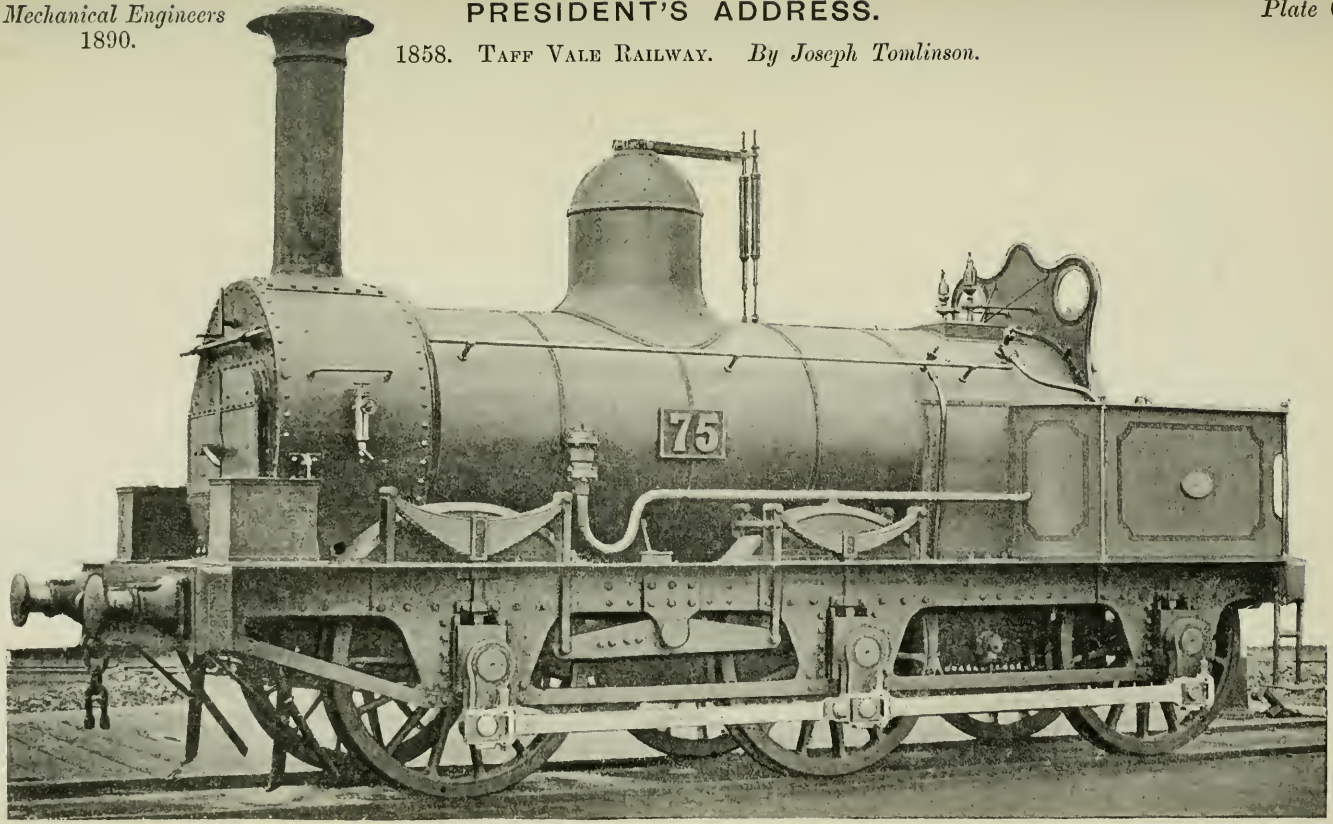


Plate 65.

1862. South Eastern Railway. *By James Cudworth.*

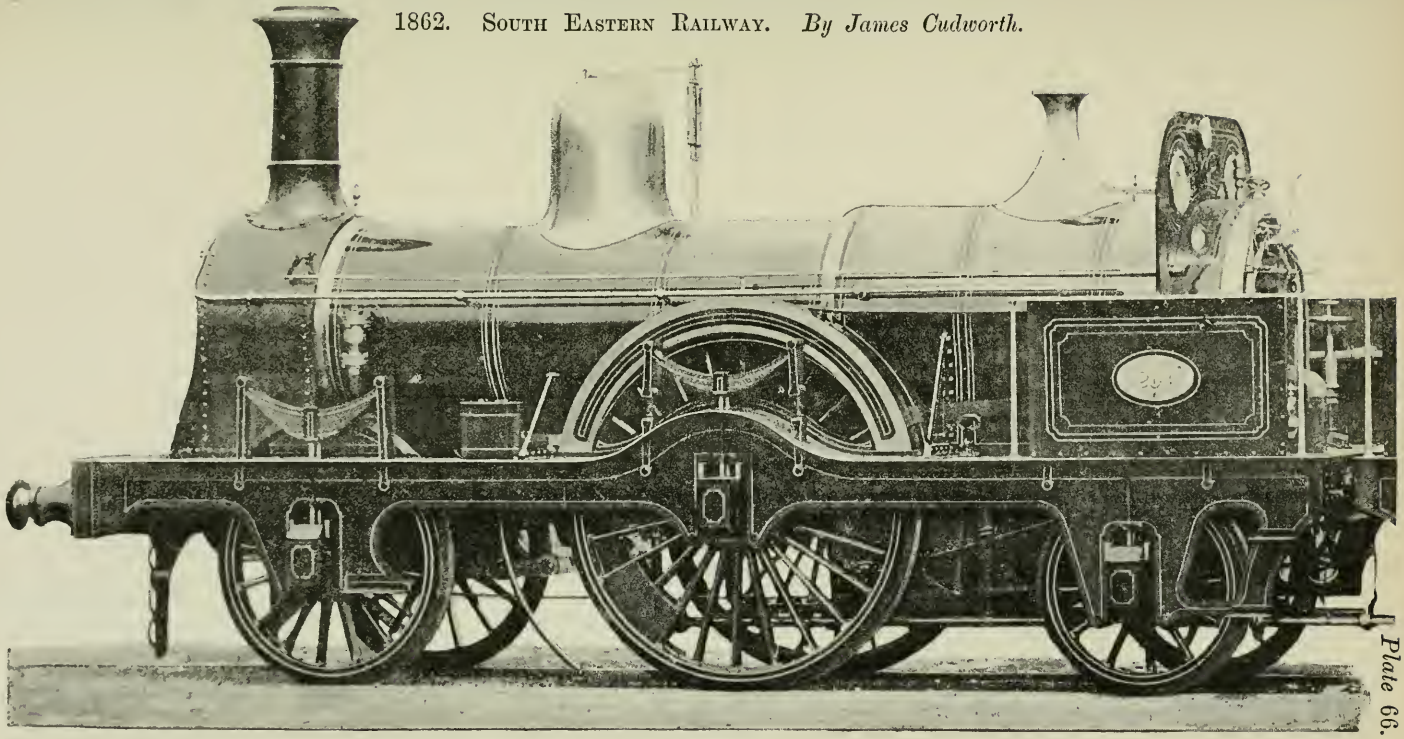


Plate 66.

1863. Midland Railway.

By Matthew Kirtley.

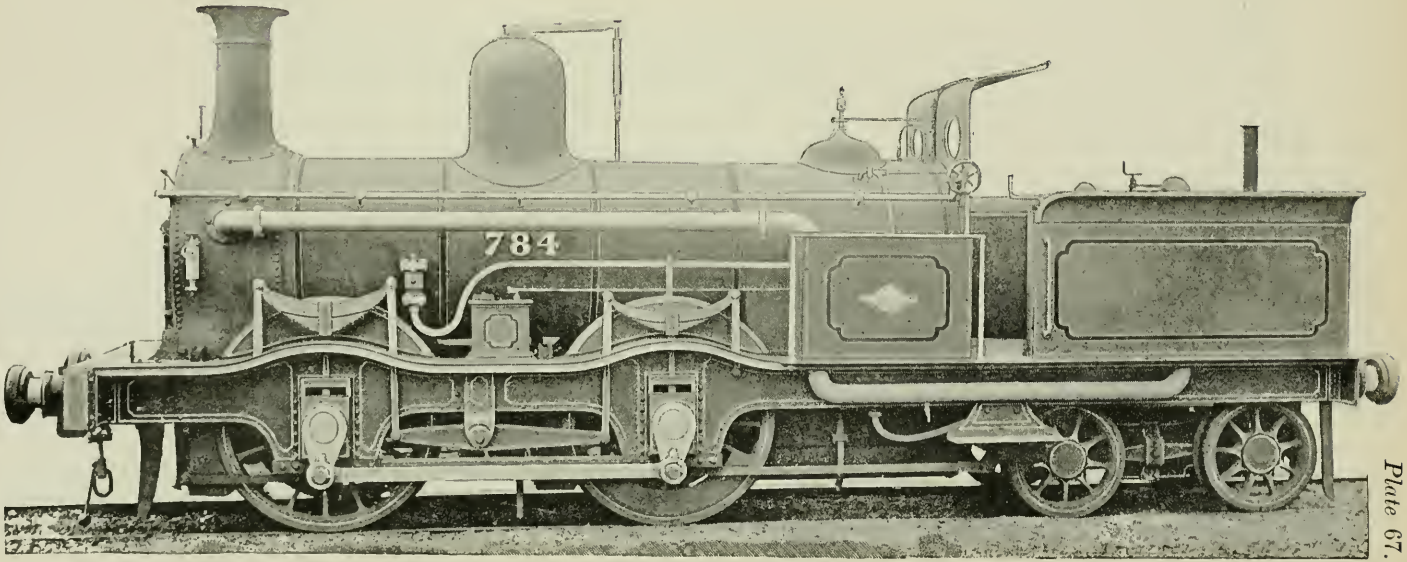
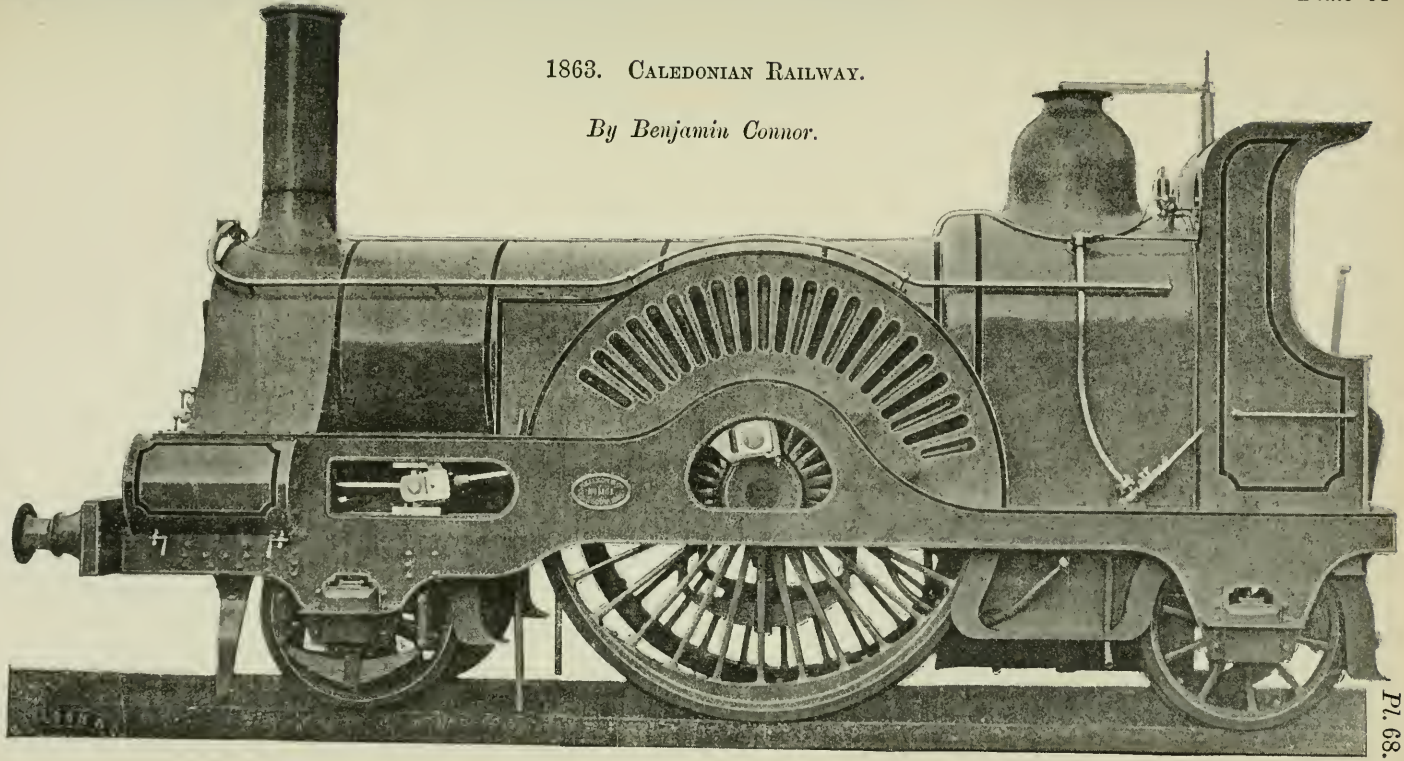


Plate 67.

1863. CALEDONIAN RAILWAY.

By Benjamin Connor.



Pl. 68.

1864. GREAT EASTERN RAILWAY.

By Robert Sinclair.

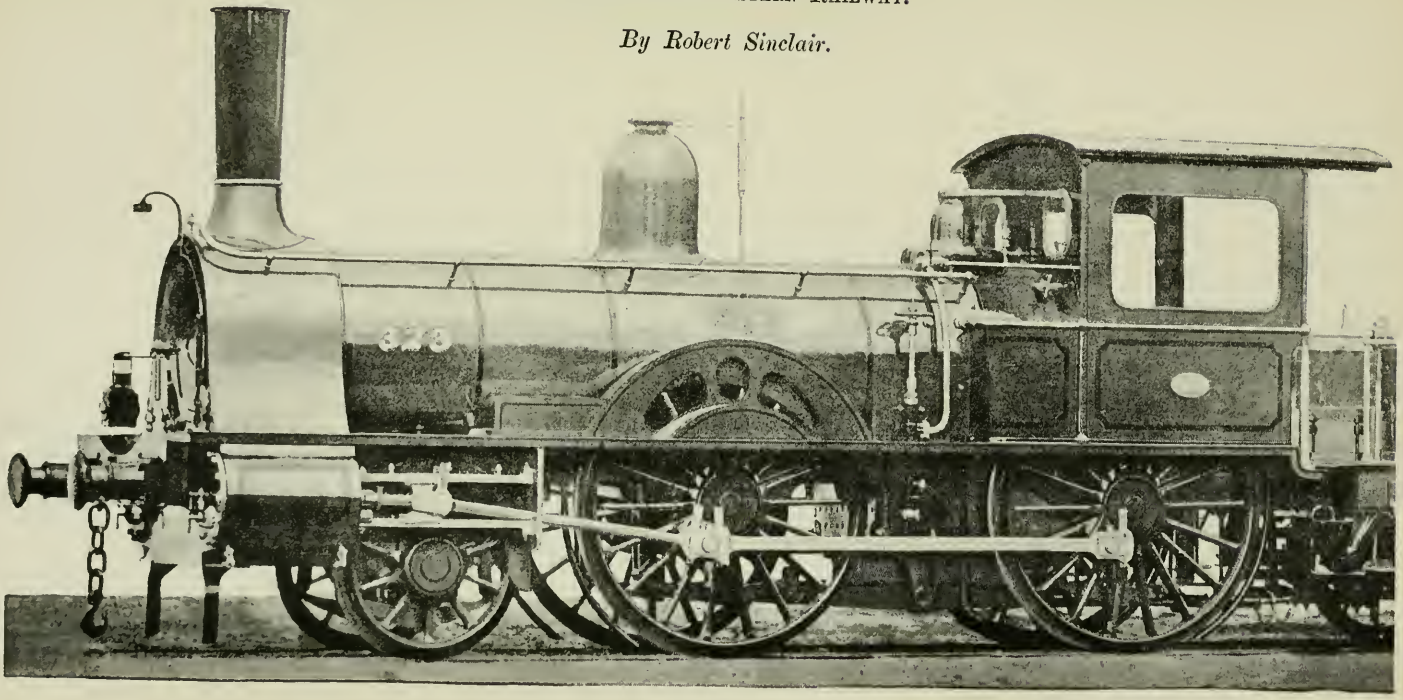


Plate 69.

1865. GREAT NORTHERN RAILWAY.

By Patrick Stirling.

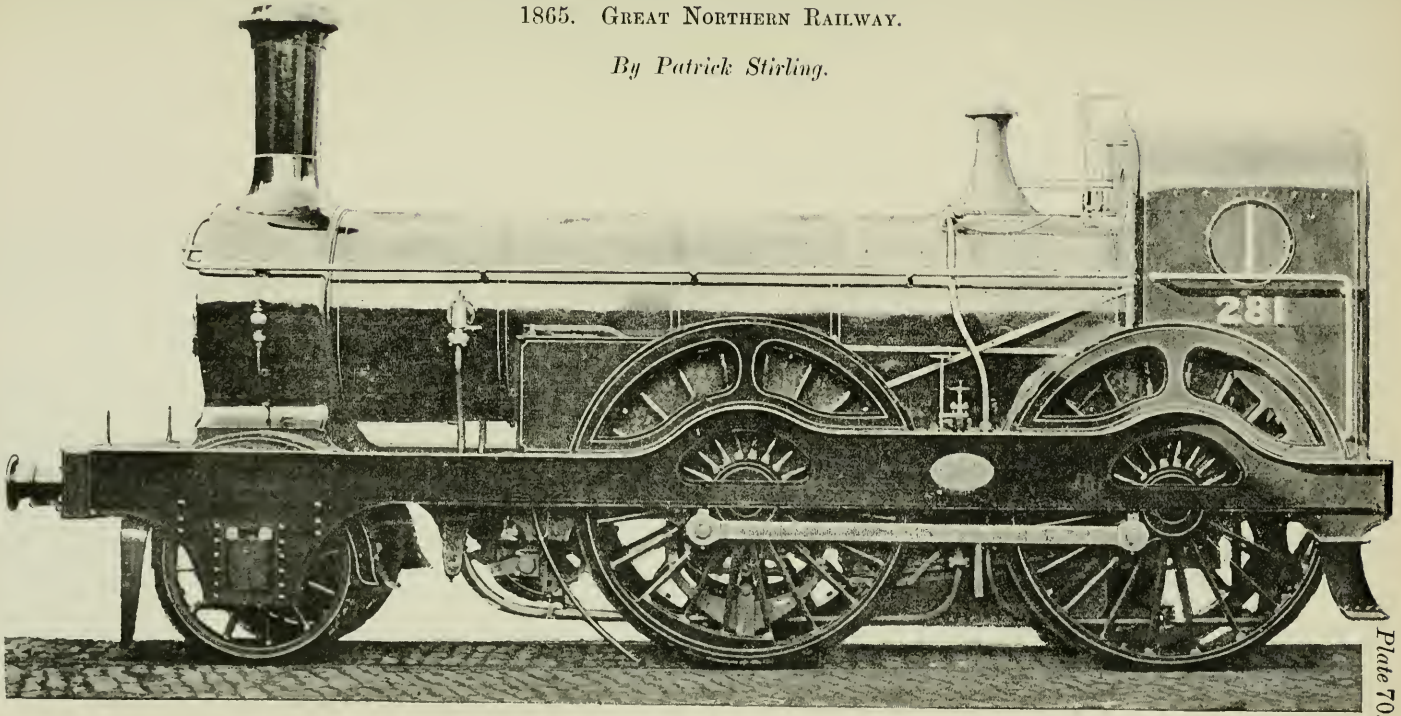


Plate 70.

1866. American Railways.

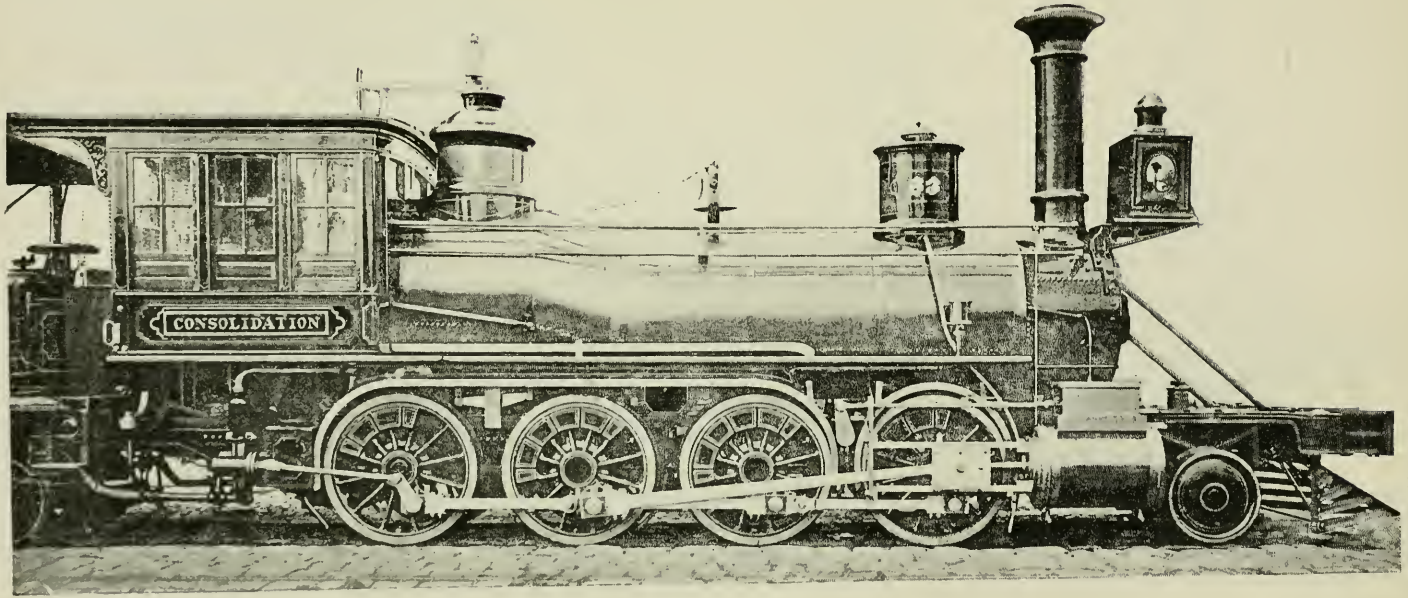


Plate 71.

1867. North Eastern and other Railways.

By Kitson and Co.

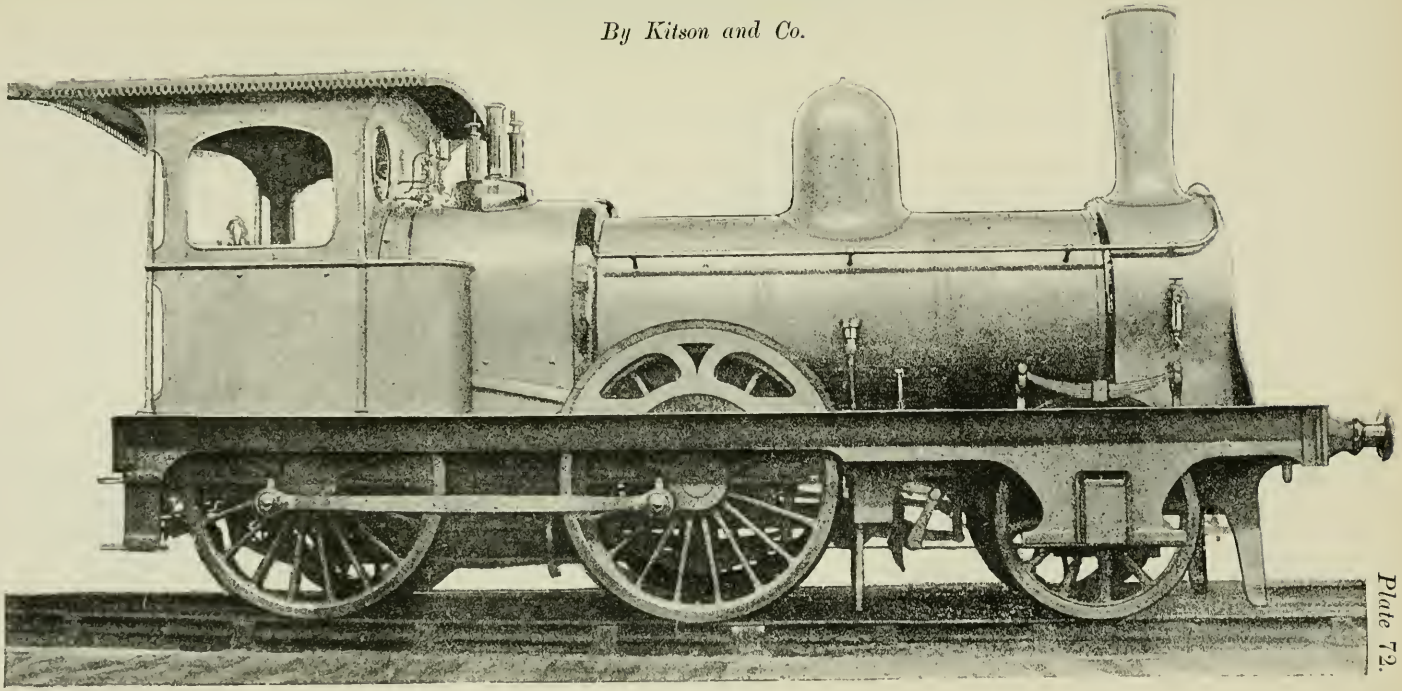


Plate 72.

1868. Foreign Railways.

By Stephenson and Co.

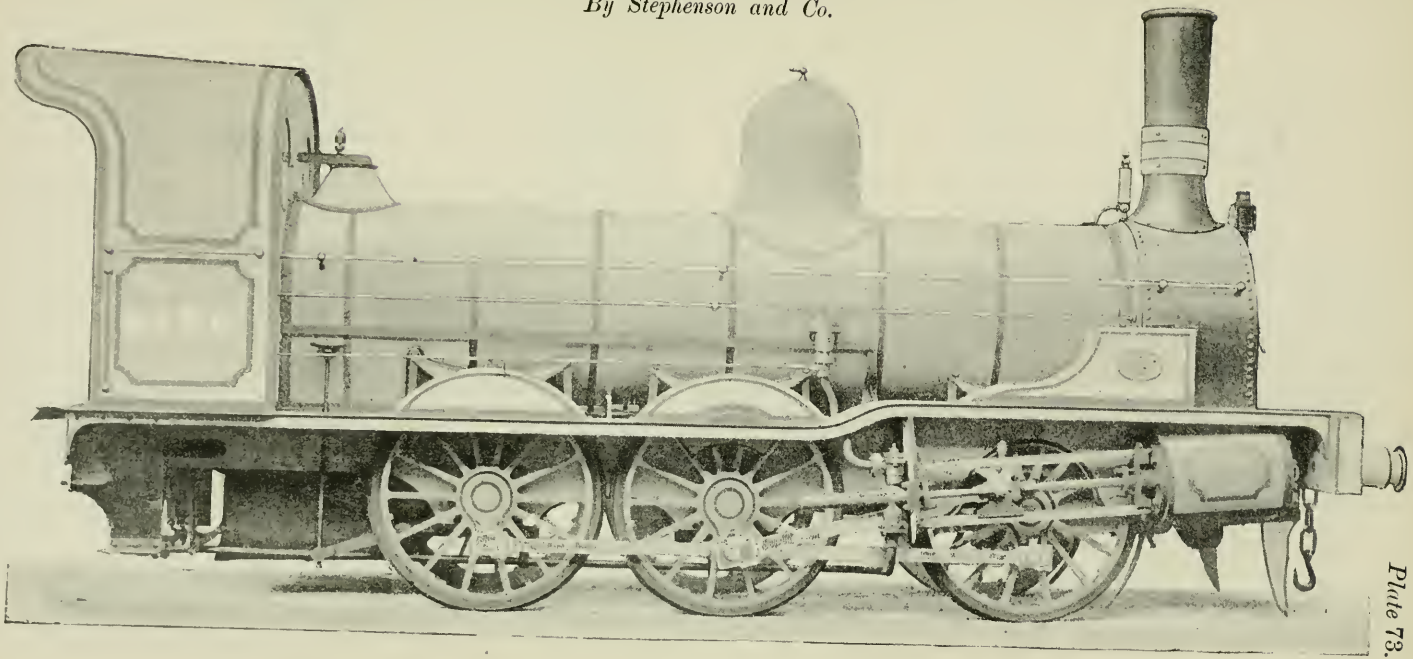


Plate 73.

1869. Caledonian Railway.

By Benjamin Connor.

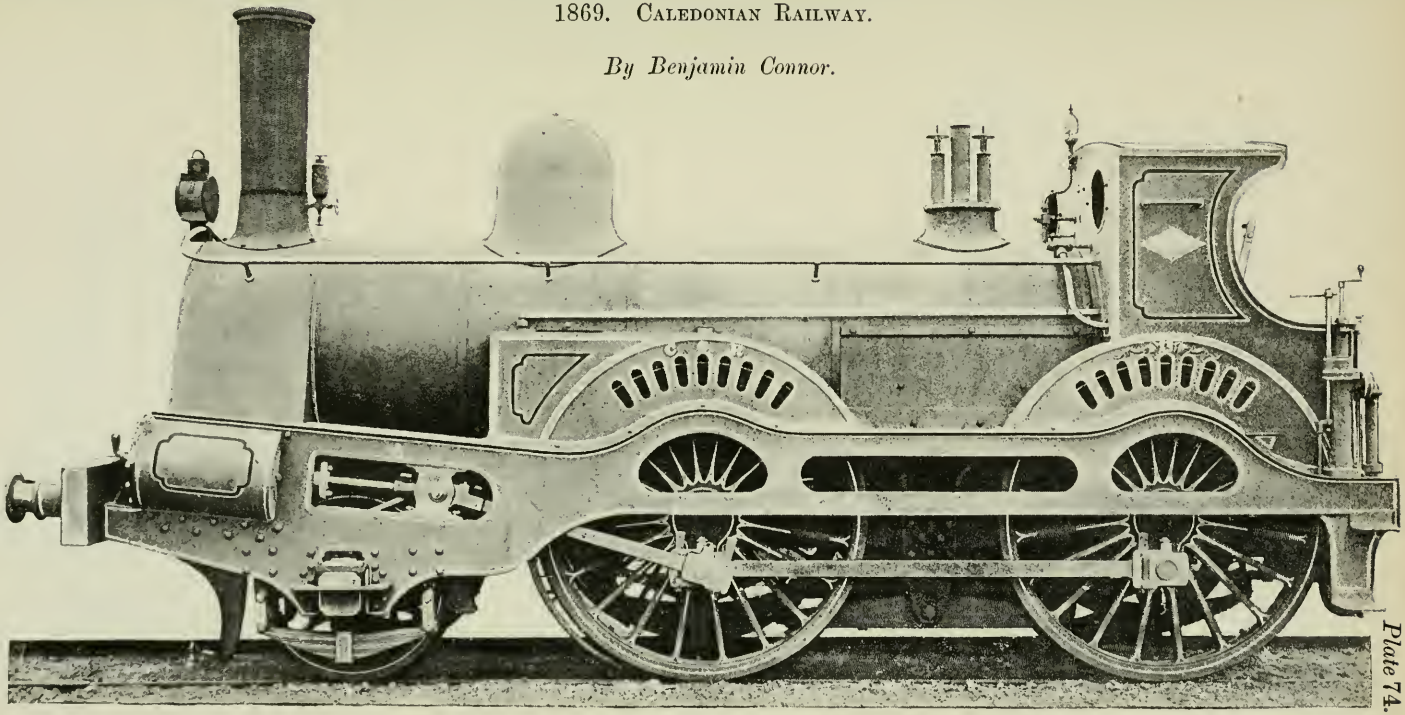


Plate 74.

1870. GREAT NORTHERN RAILWAY.

By Patrick Stirling.

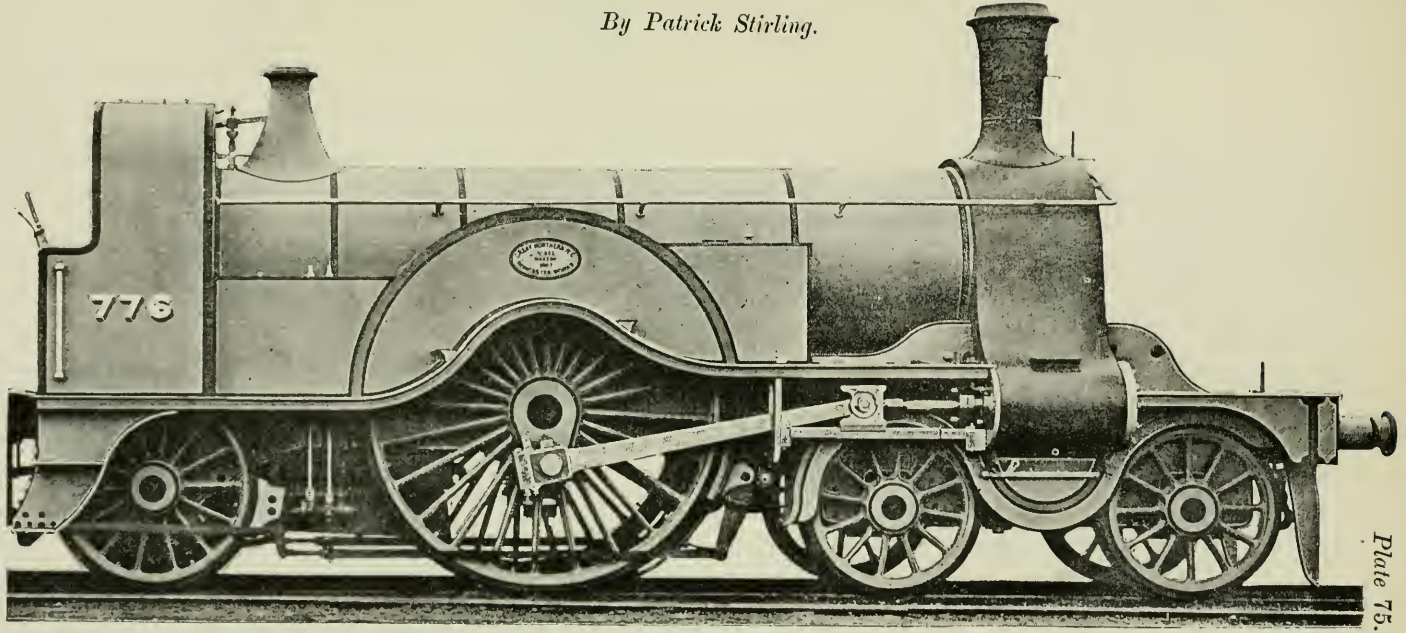


Plate 75.

1873. London and North Western Railway. *By Francis W. Webb.*

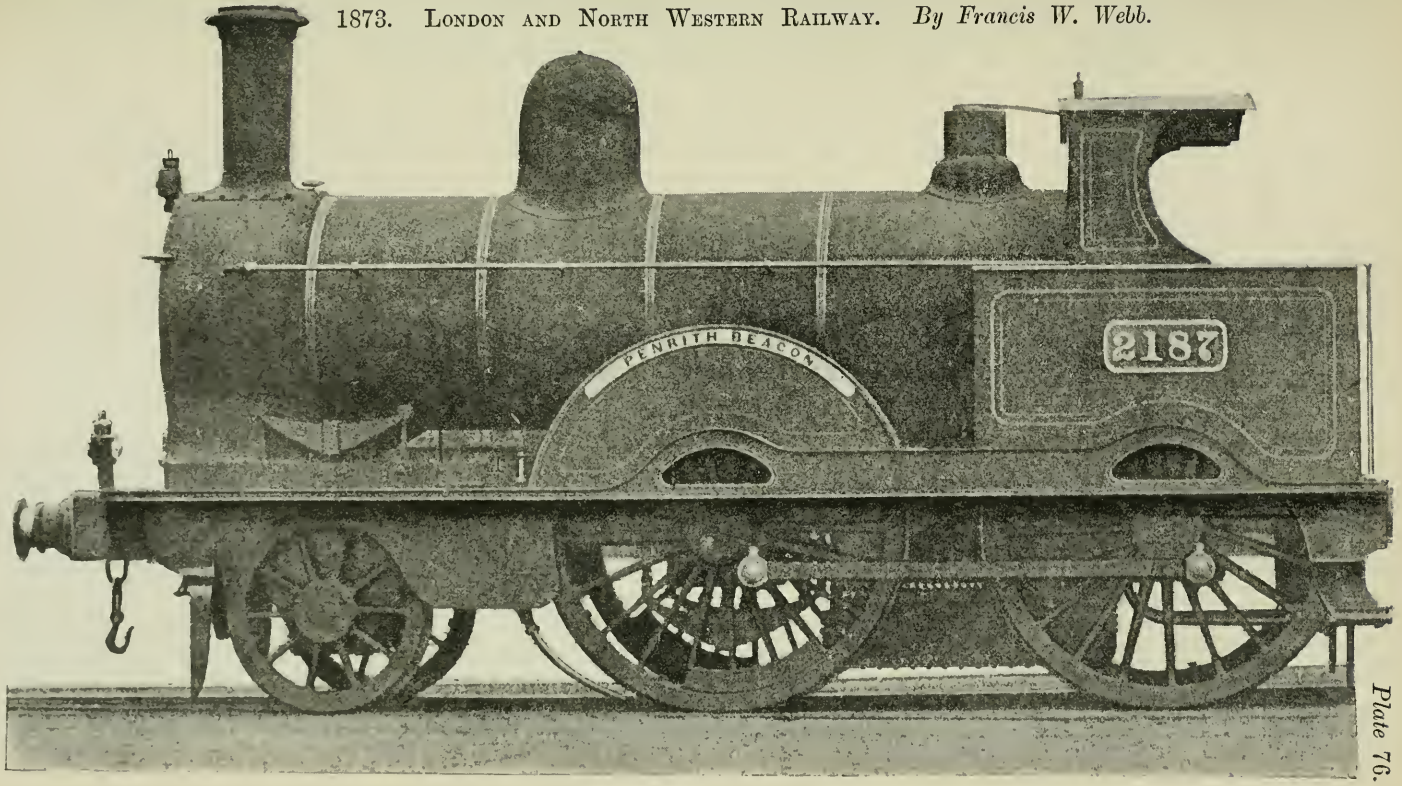


Plate 76.

1875. Great Western Railway. *By Joseph Armstrong.*

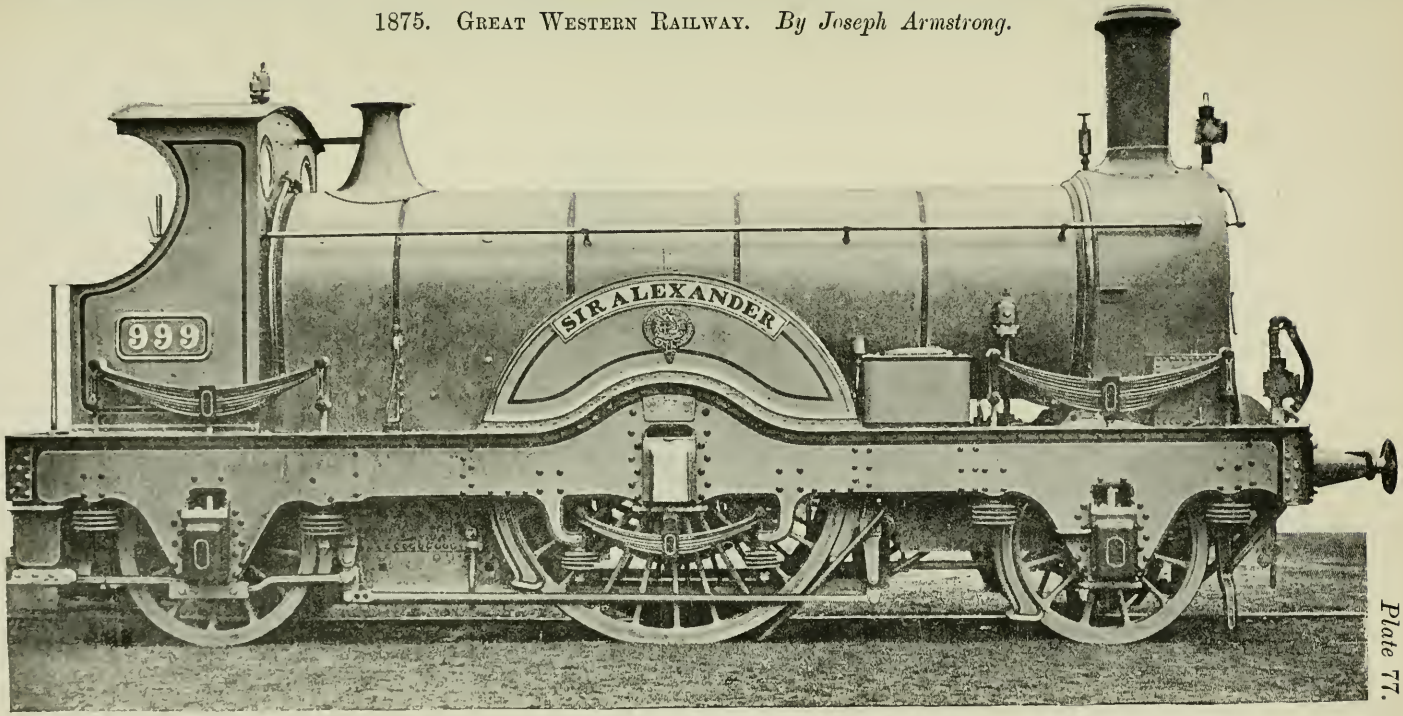


Plate 77.

1877. London Brighton and South Coast Railway.

By William Stroudley.

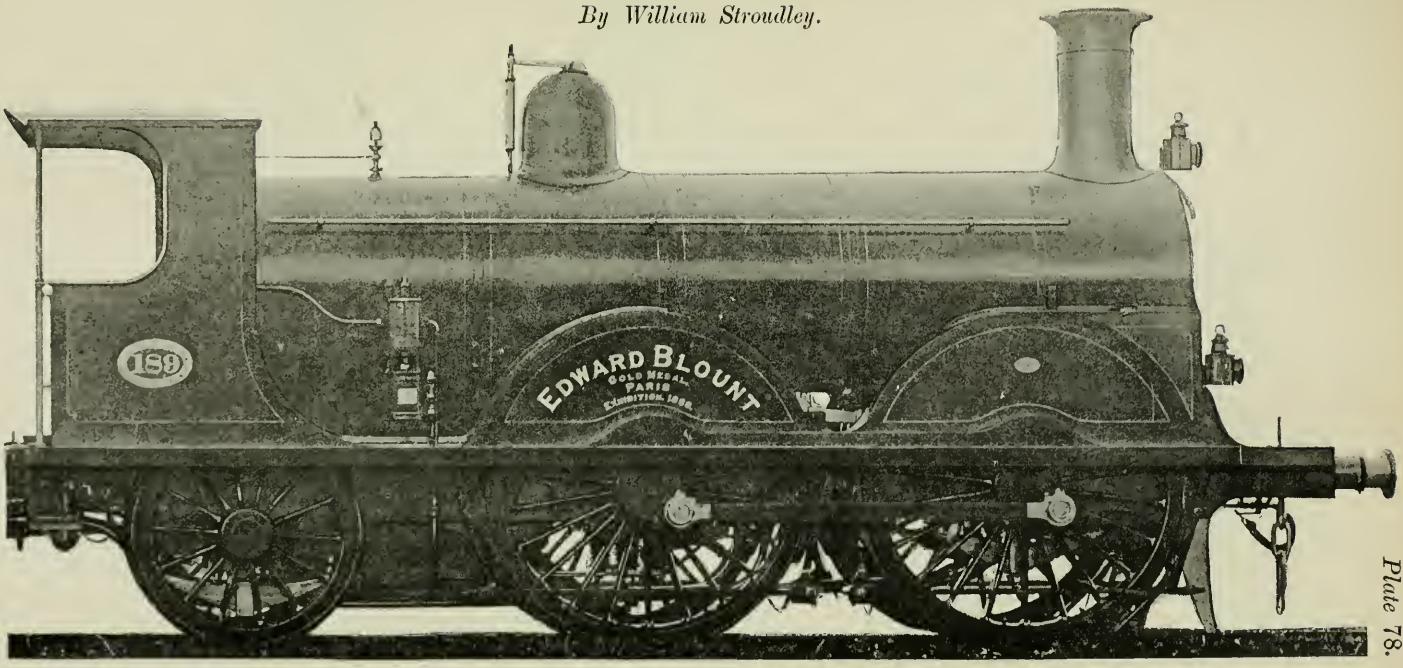


Plate 78.

1881. London and North Western Railway. Compound.

By Francis W. Webb.

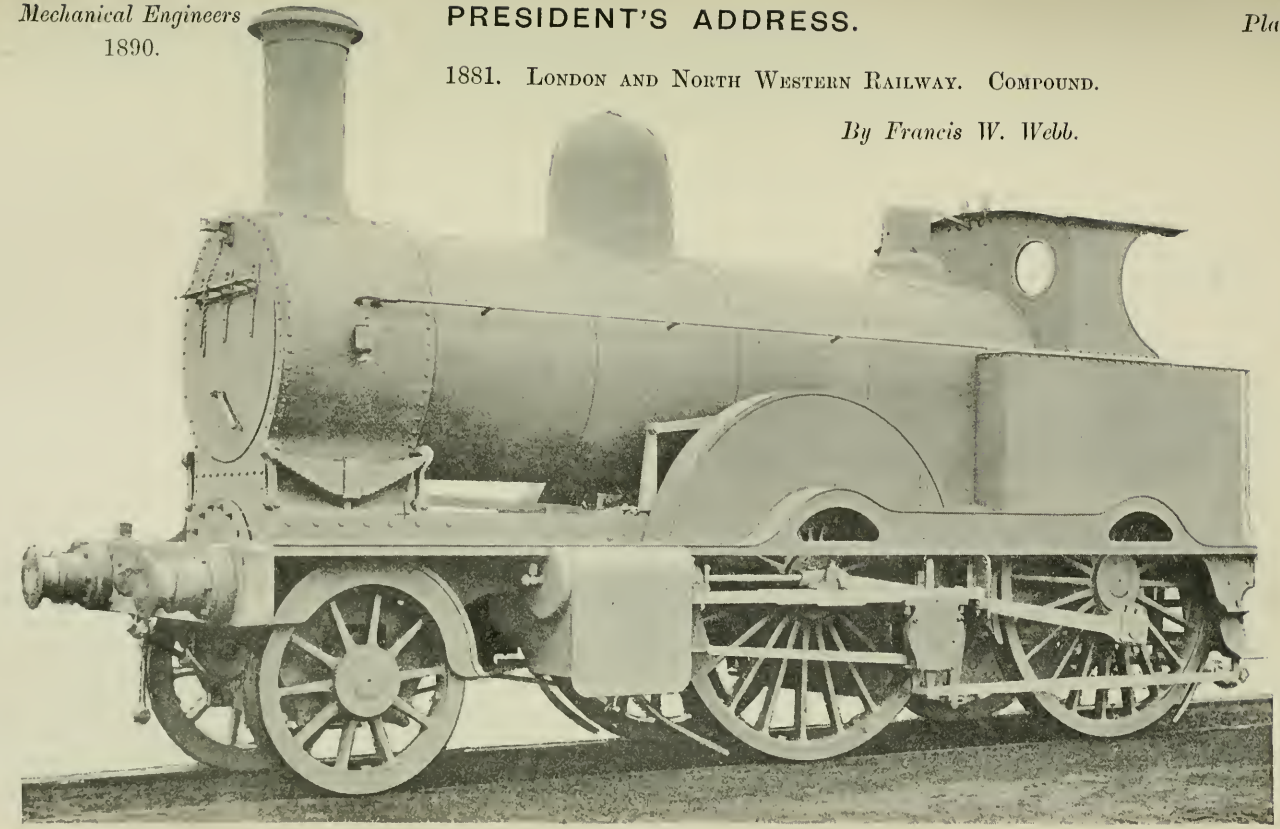


Plate 79.

1881. London and South Western Railway.

By William Adams.

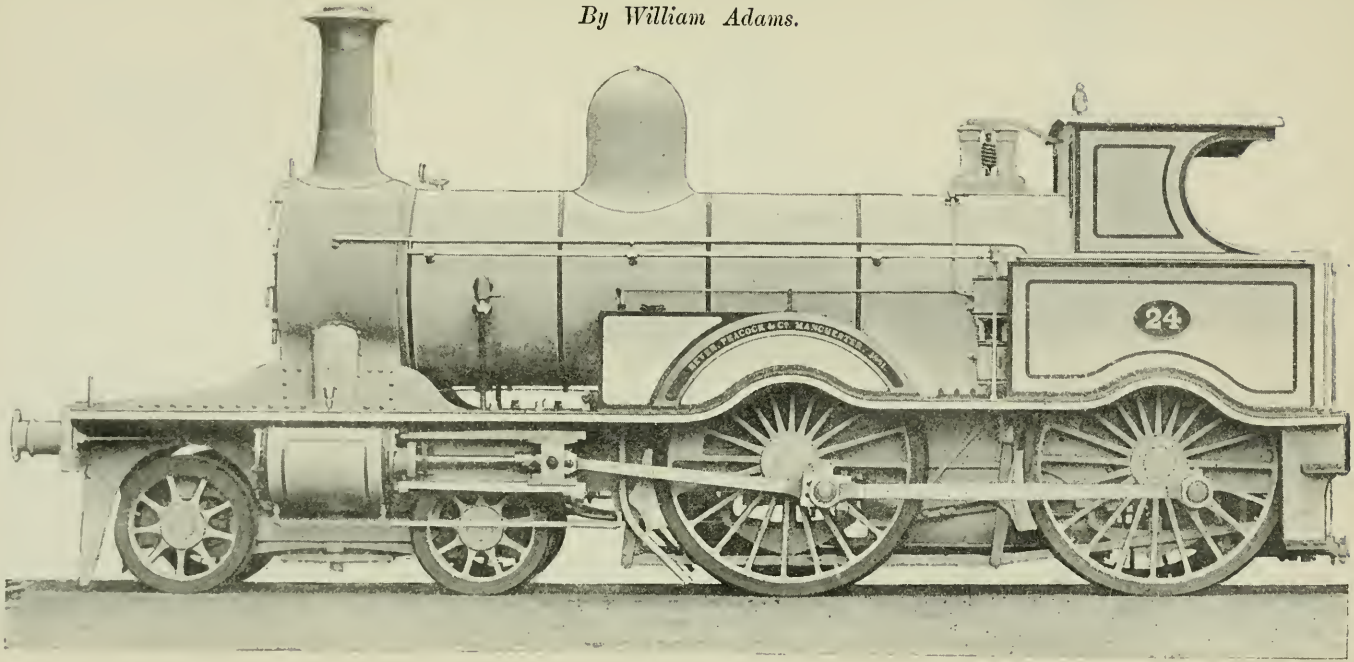


Plate 80.

1885. MIDLAND RAILWAY.

By Samuel Waite Johnson.

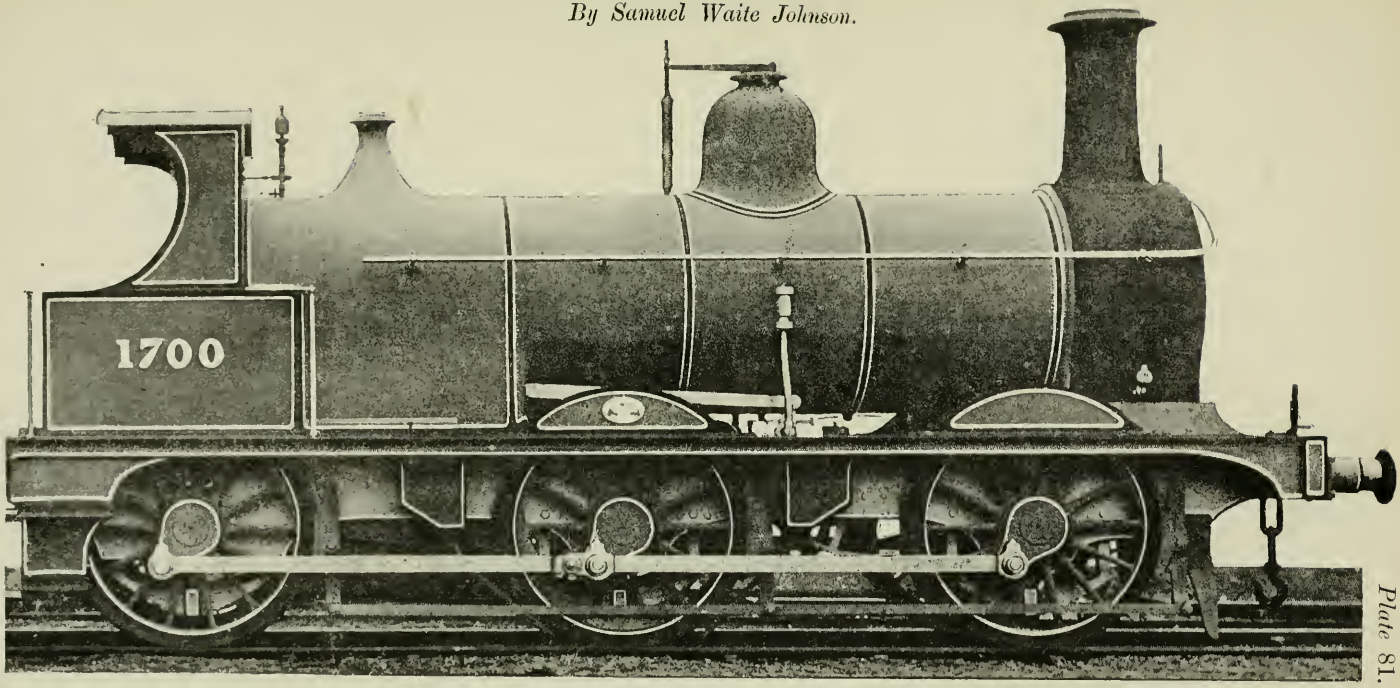


Plate 81.

1886. Midland Railway.

By Samuel Waite Johnson.

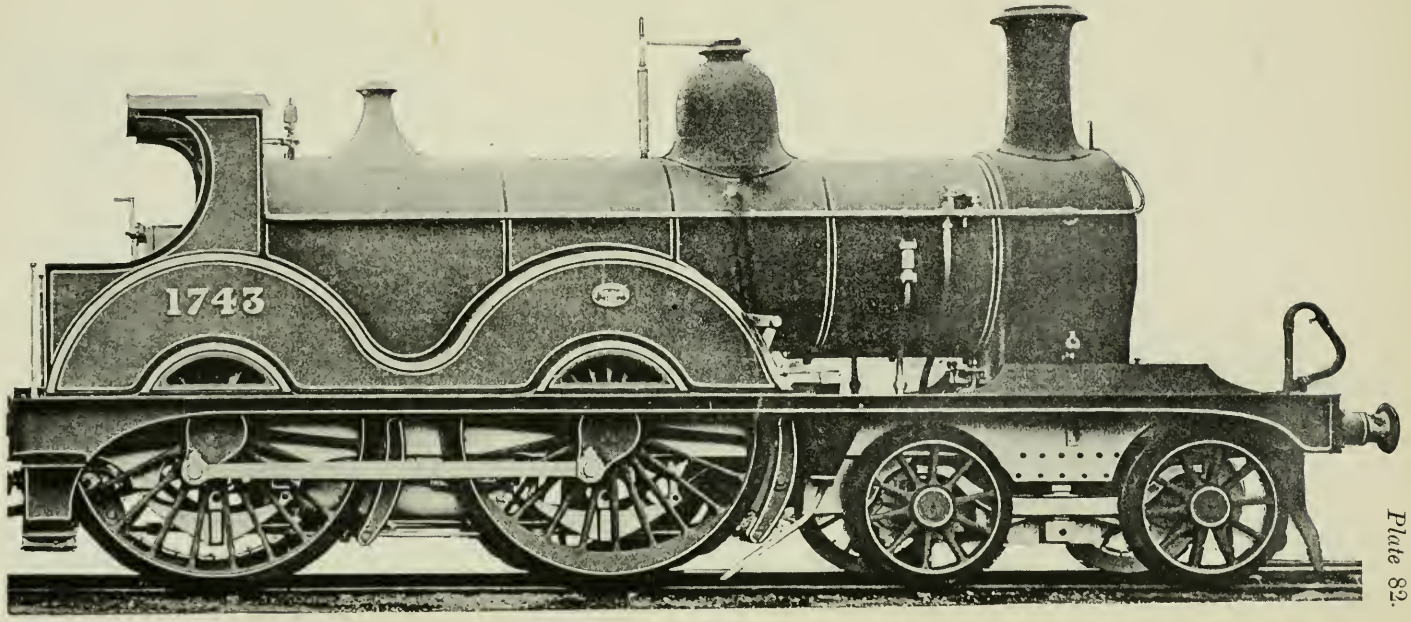


Plate 82.

1887. North Eastern Railway. Compound.

By Thomas W. Worsdell.

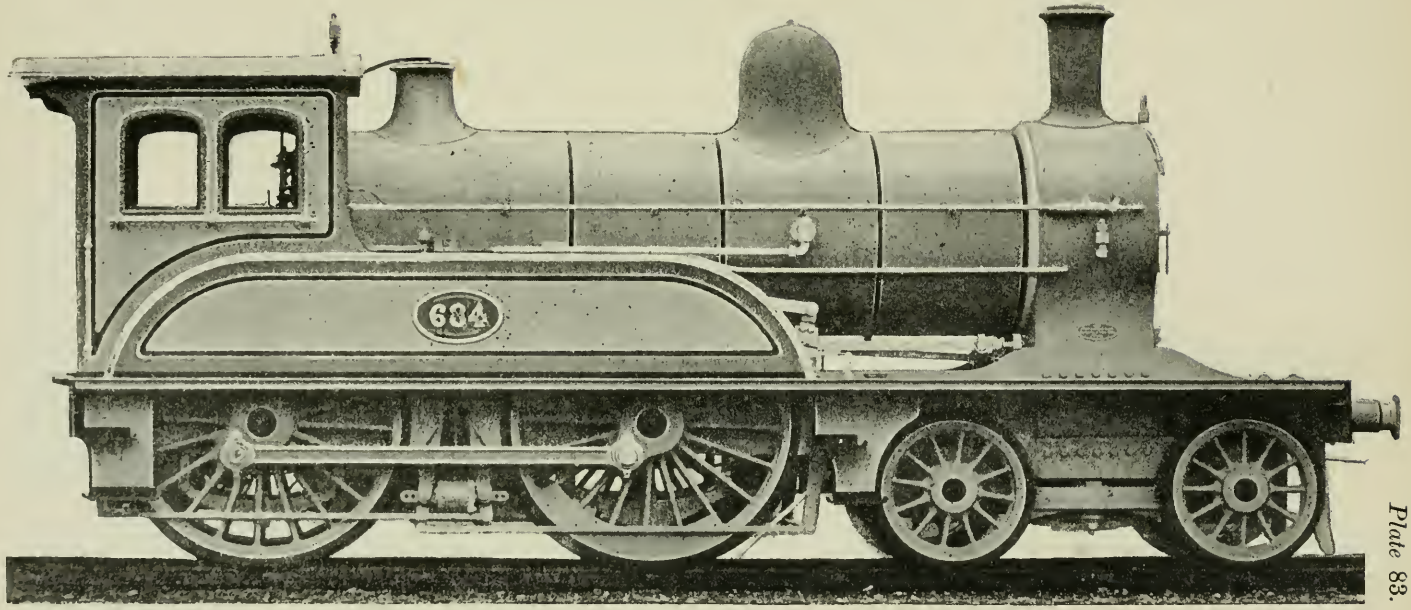


Plate 83.

1889. North Eastern Railway. Compound.

By Thomas W. Worsdell.

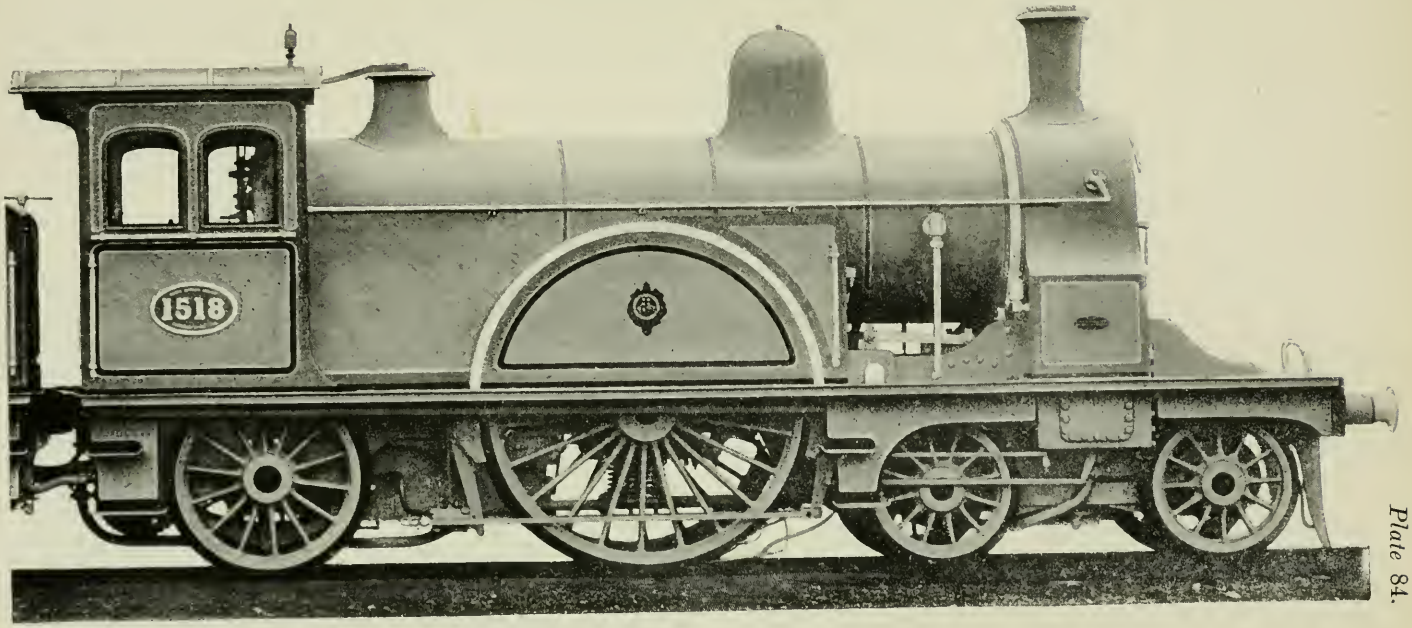


Plate 84.

1889. Midland Railway.

By Samuel Waite Johnson.

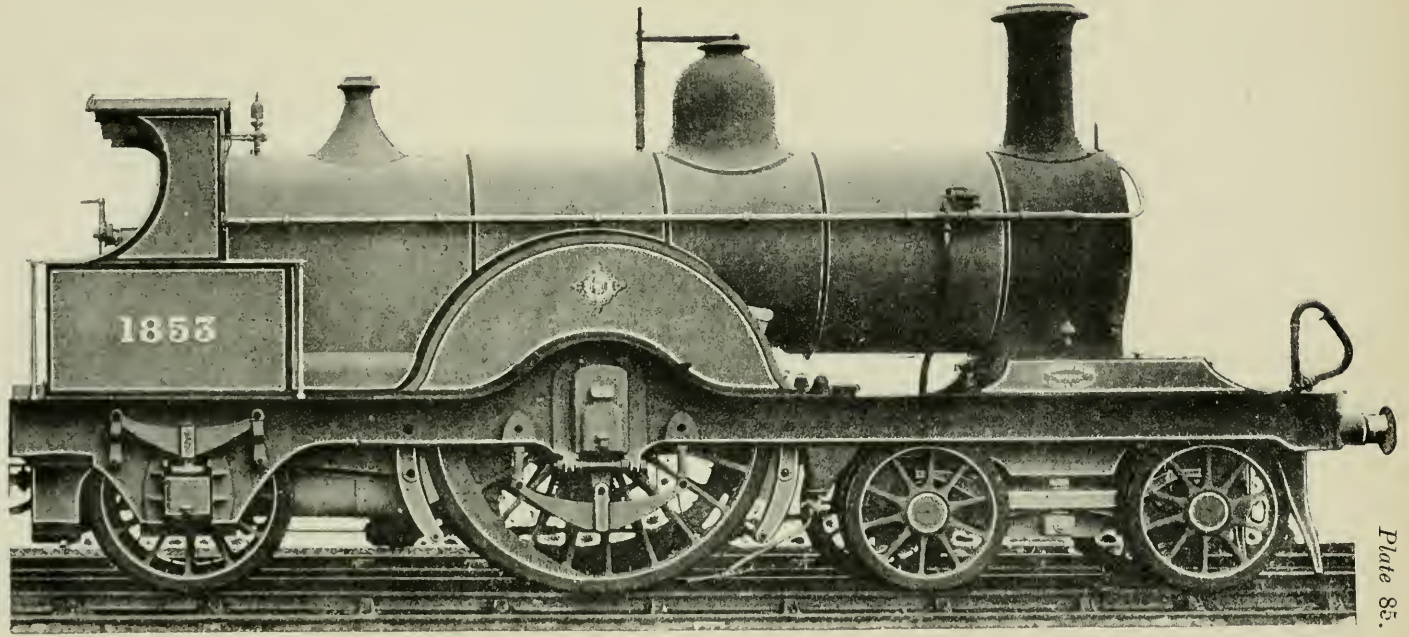


Plate 85.

1889. Caledonian Railway.

By Dugald Drummond.

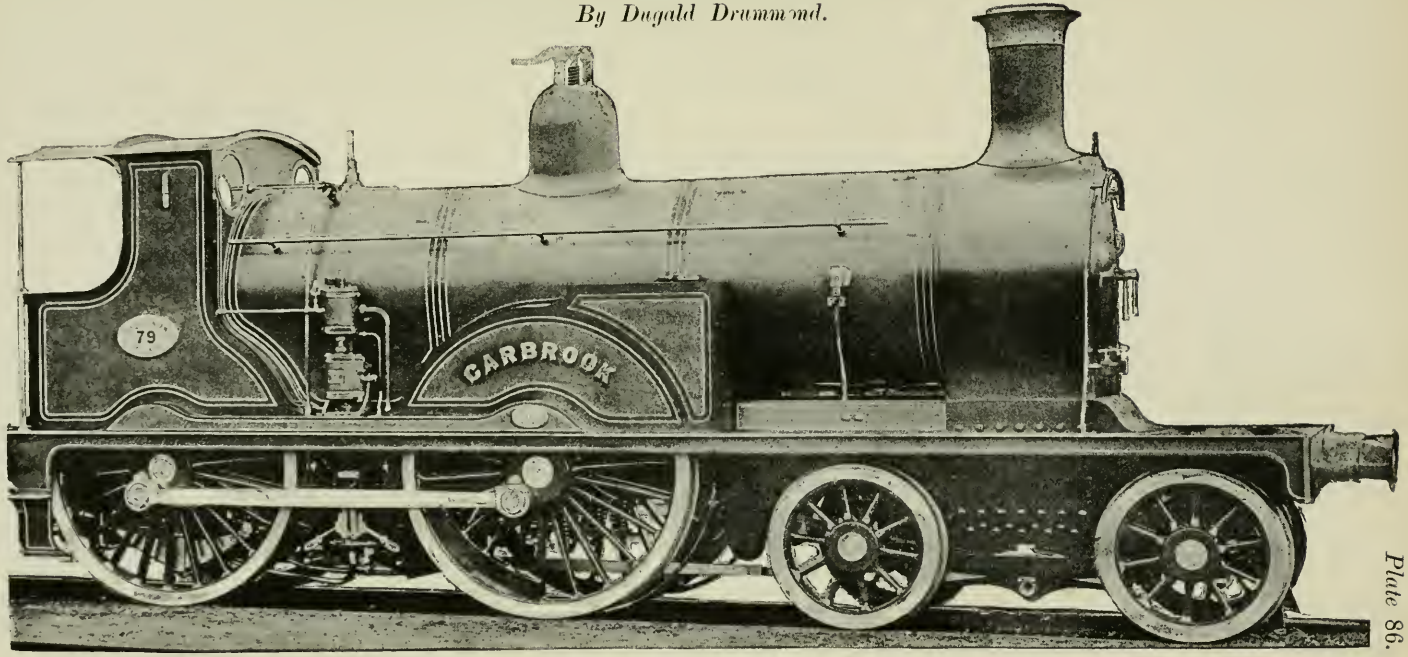


Plate 86.

Feed-Water Measuring Tanks. Fig. 1. *Plan.*

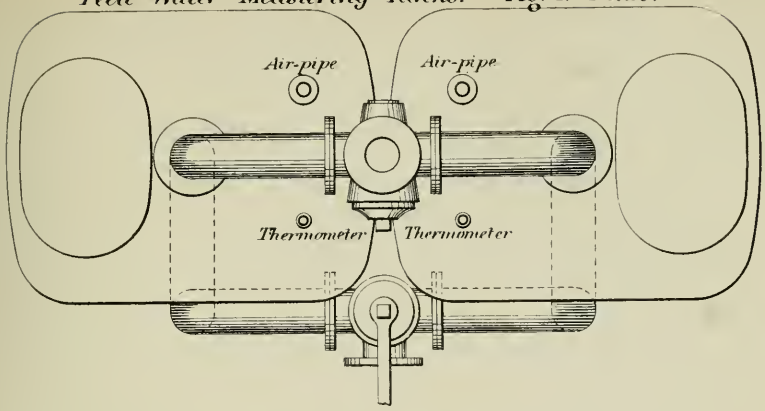
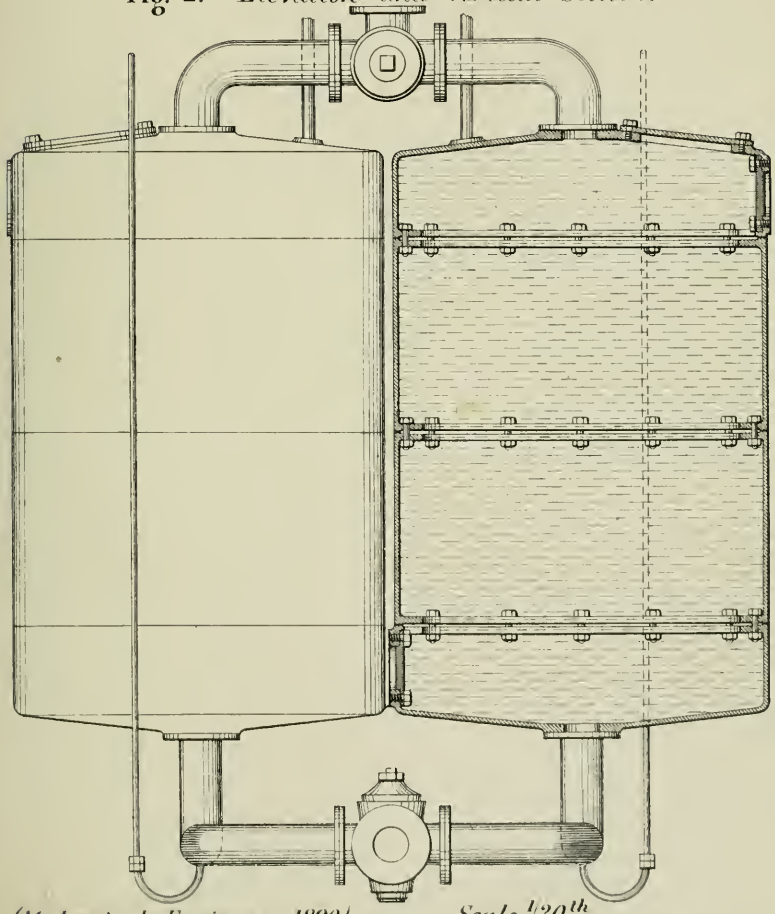


Fig. 2. *Elevation and Vertical Section.*

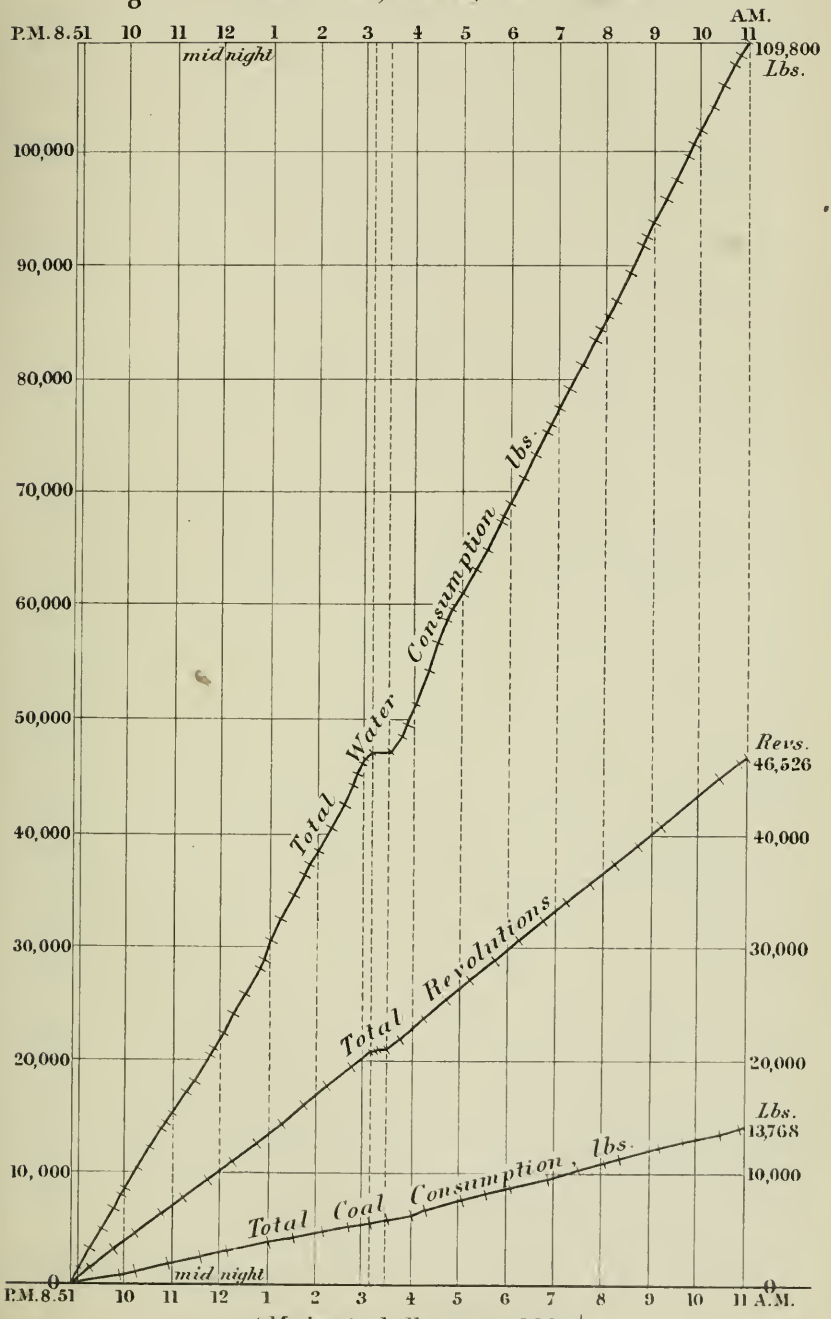


(Mechanical Engineers 1890) *Scale 1/20th*

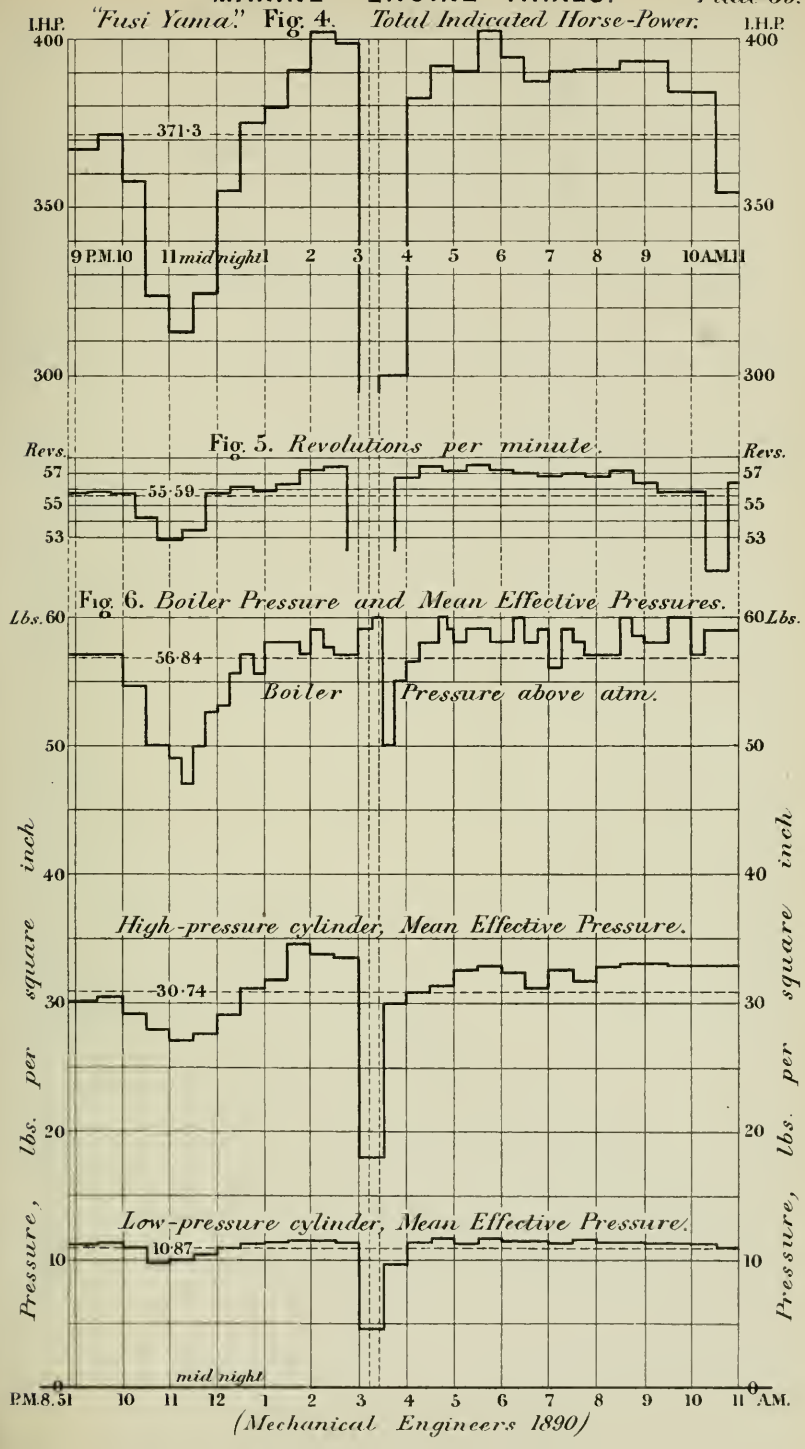
Ins. 12 6 0 1 2 3 4 5 Feet.

Trial of the "Fusi Yama."

Fig. 3. *Total Coal, Water, and Revolutions.*



(Mechanical Engineers 1890)



(Mechanical Engineers 1890)

"Fusi Yama" Indicator Diagrams, Set 2.

Revs. 55·9 per min. Total I.H.P. 371·2.

Fig. 7. *High-pressure cylinder. I.H.P. 164·1.*

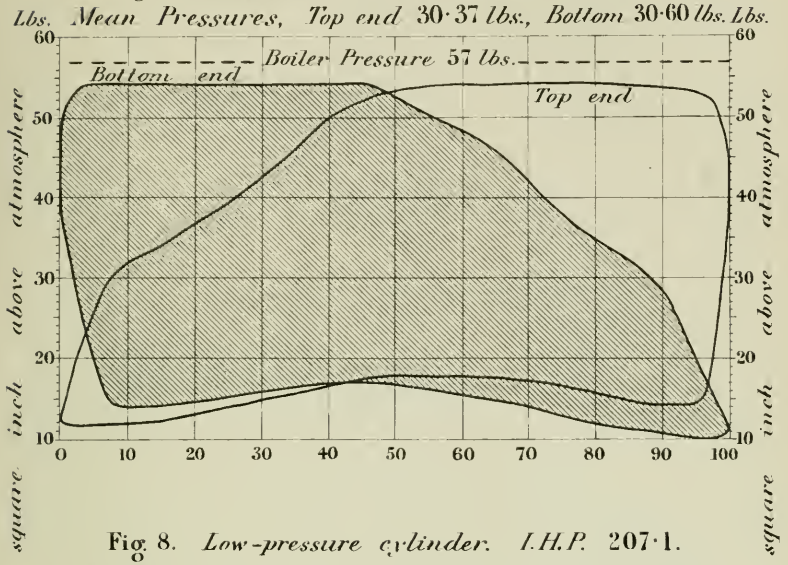
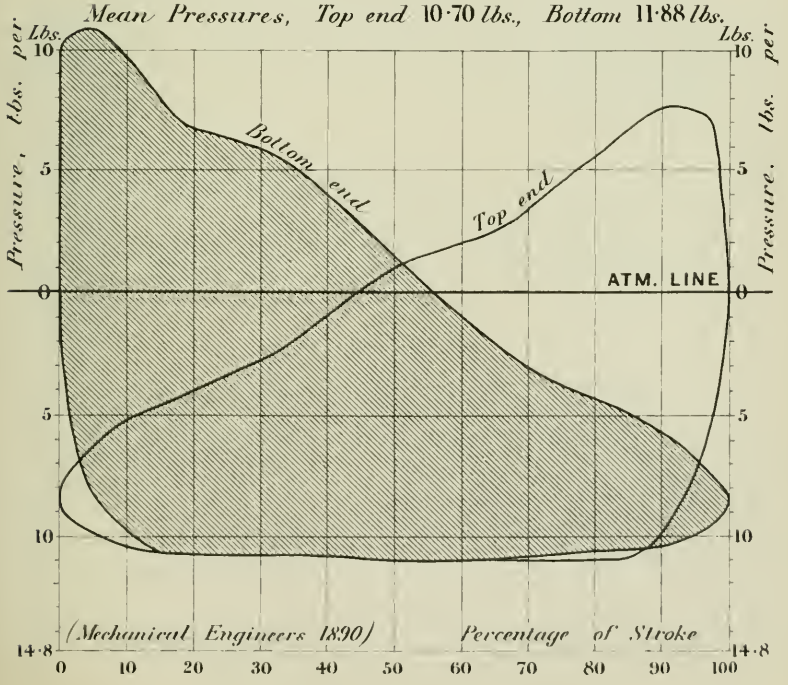


Fig. 8. *Low-pressure cylinder. I.H.P. 207·1.*



Trial of the "Fusi Yama."

Fig. 9. *Temperature of Chimney Gases.*

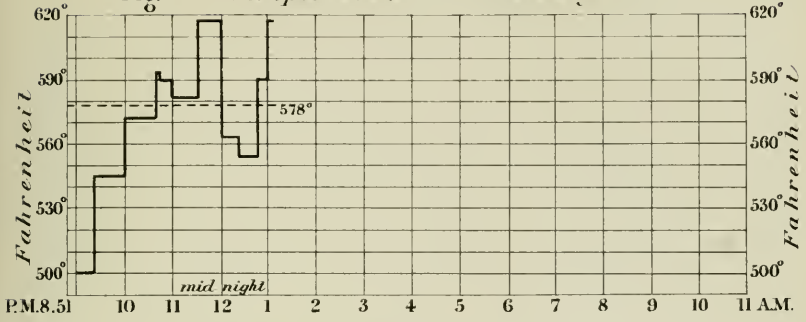


Fig. 10. *Mean Indicator Diagrams.*

Mean Boiler Pressure 56·84 lbs.

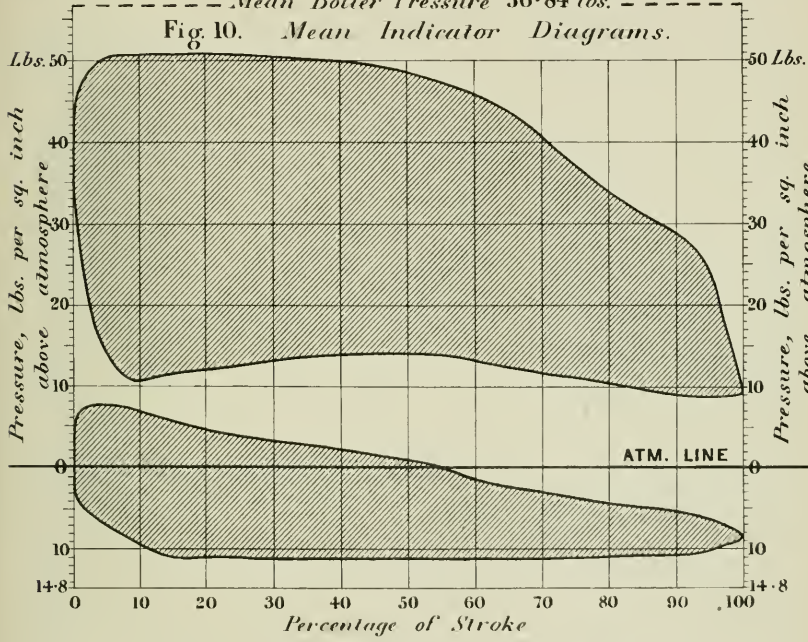
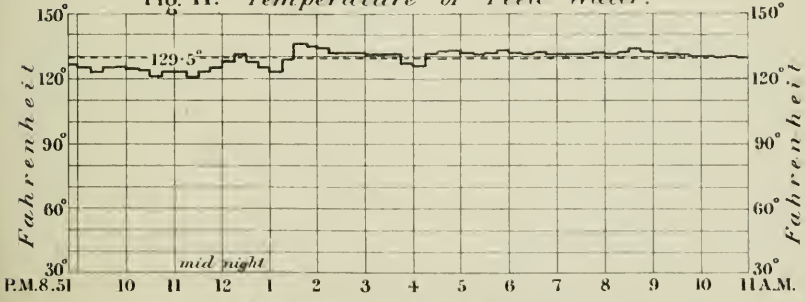


Fig. 11. *Temperature of Feed-Water.*

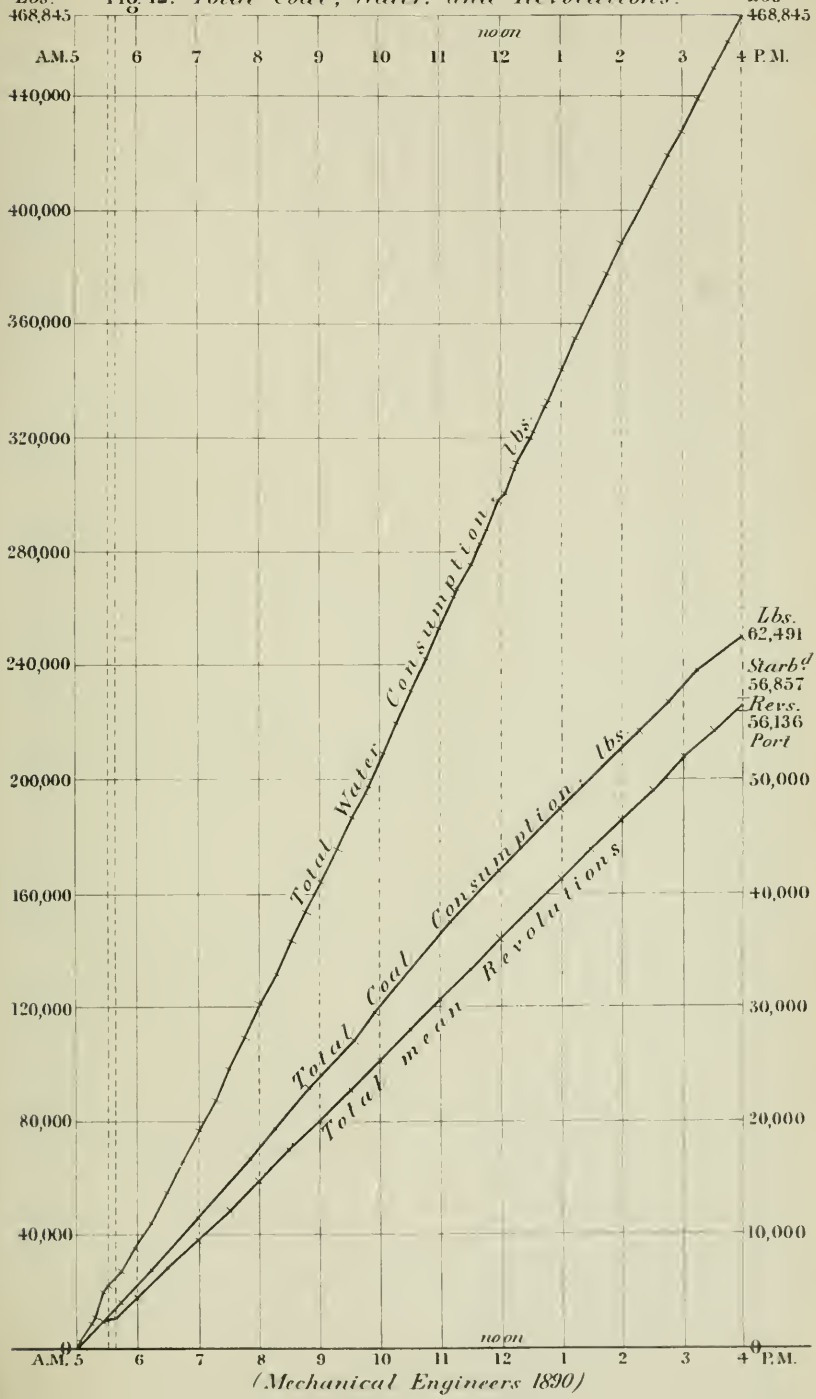


(Mechanical Engineers 1890)

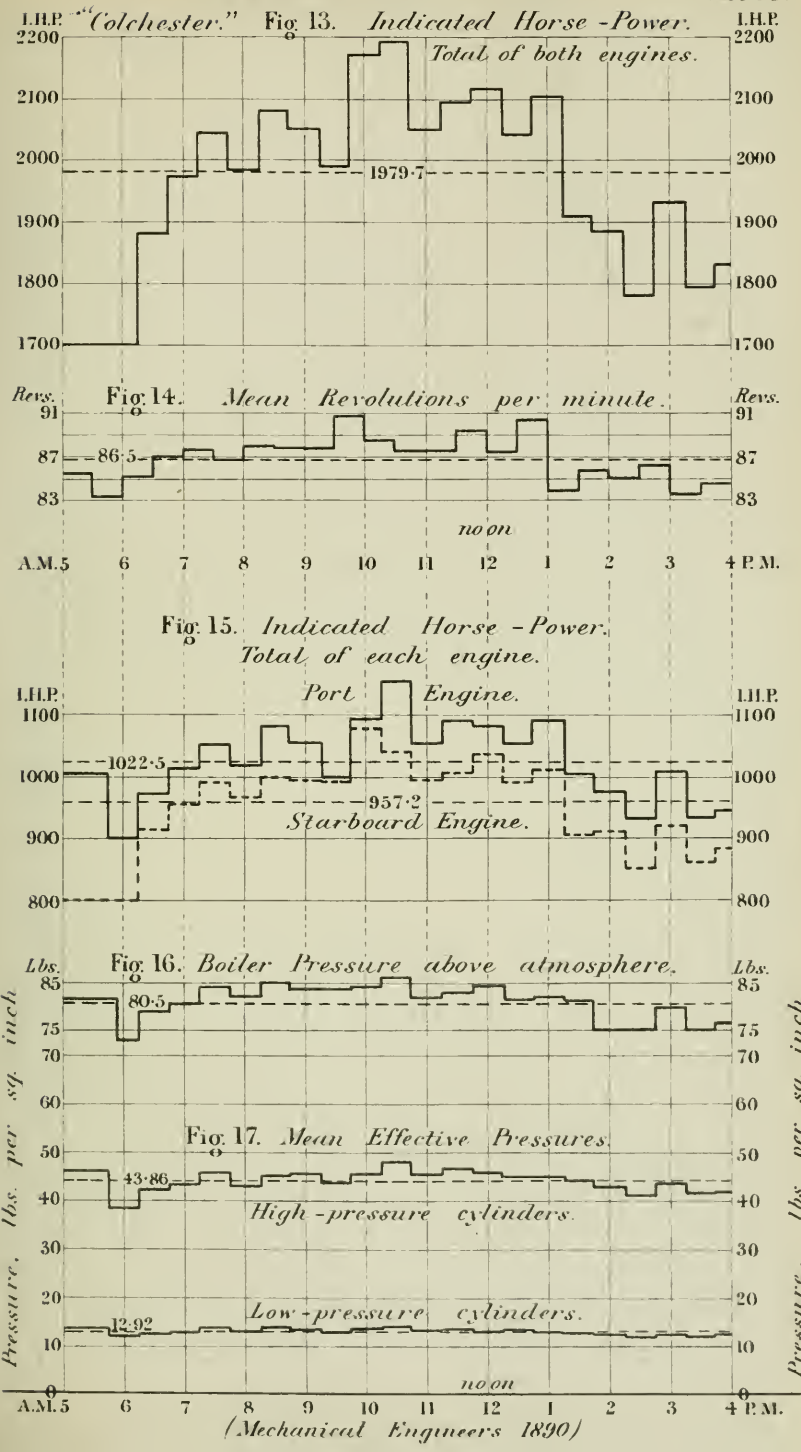
MARINE-ENGINE TRIALS.

Trial of the "Colchester."

Fig 12. *Total Coal, Water, and Revolutions.*



(Mechanical Engineers 1890)



(Mechanical Engineers 1890)

"Colchester" Indicator Diagrams, Set 6, Port Engine.

Revs. 86·3 per min. Total I.H.P. 1017·2.

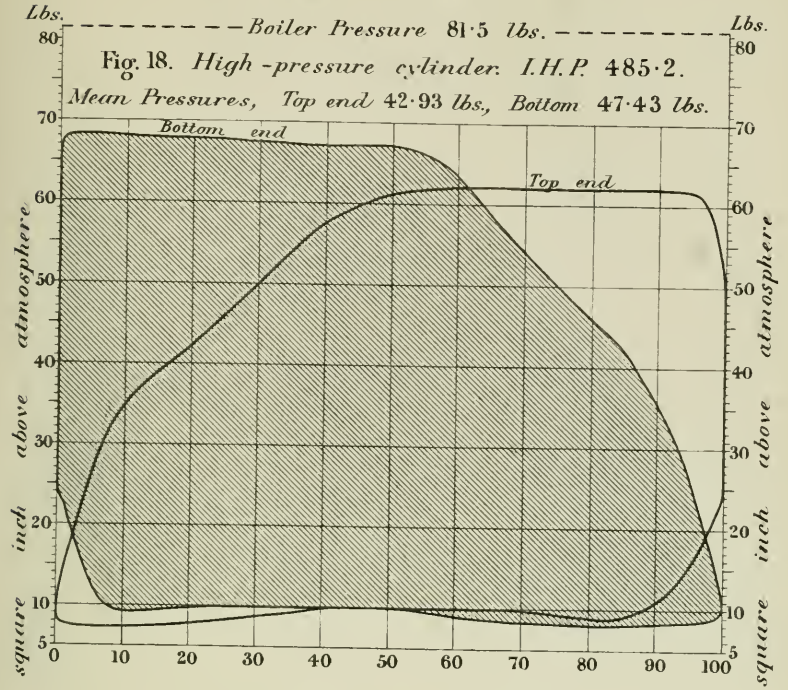


Fig. 18. *High-pressure cylinder. I.H.P.* 485·2.

Mean Pressures, Top end 42·93 *lbs., Bottom* 47·43 *lbs.*

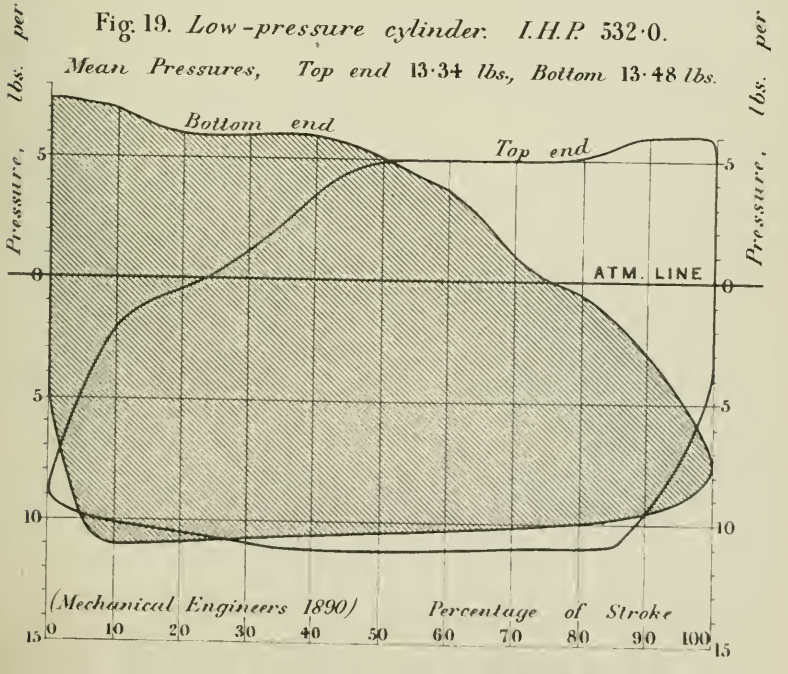


Fig. 19. *Low-pressure cylinder. I.H.P.* 532·0.

Mean Pressures, Top end 13·34 *lbs., Bottom* 13·48 *lbs.*

"Colchester" Indicator Diagrams, Set 6, Starboard Engine.

Revs 87·2 *per min. Total I.H.P.* 964·7.

Fig. 20. *High-pressure cylinder. I.H.P.* 459·6.

Mean Pressures, Top end 39·6 *lbs, Bottom* 45·12 *lbs.*

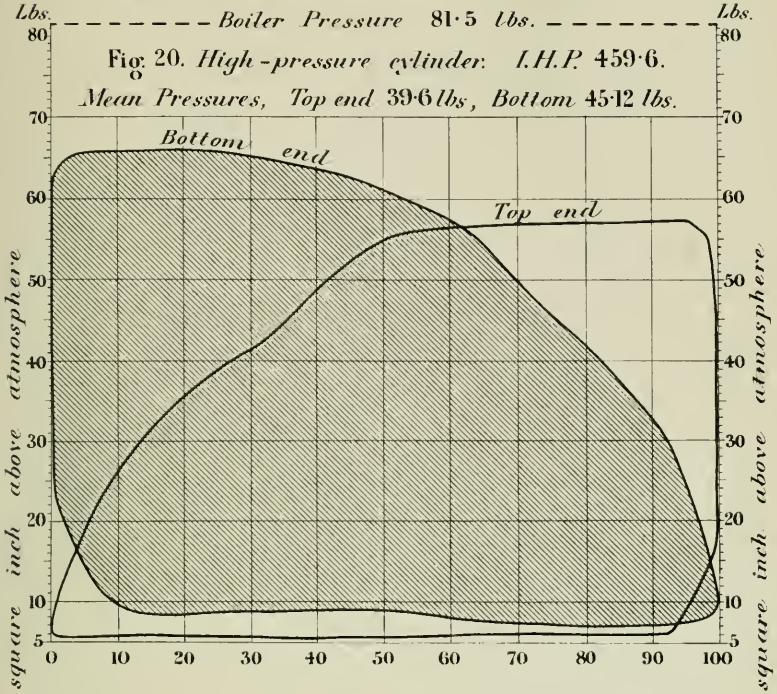
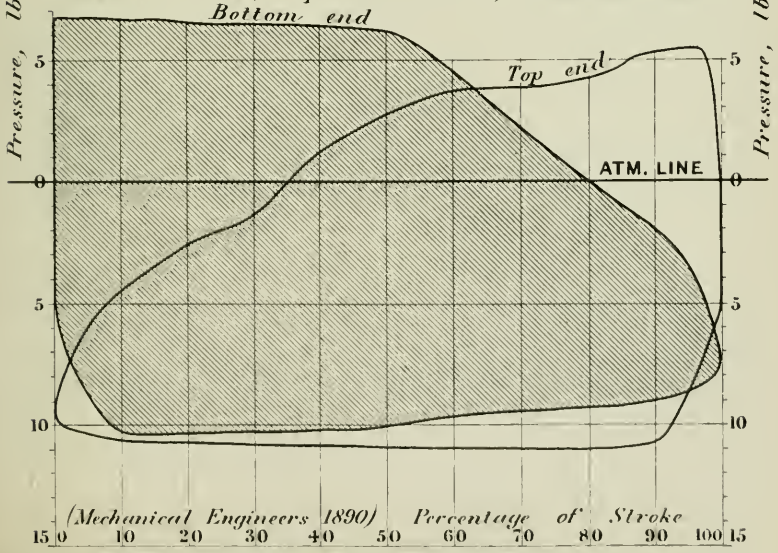


Fig. 21. *Low-pressure cylinder. I.H.P.* 505·1.

Mean Pressures, Top end 11·82 *lbs., Bottom* 13·37 *lbs.*



(Mechanical Engineers 1890)

Trial of the "Colchester."

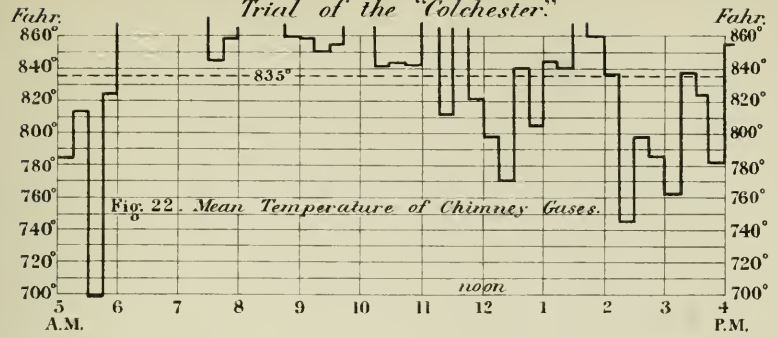


Fig. 22. *Mean Temperature of Chimney Gases.*

Fig. 23. *Mean Indicator Diagrams.*

Mean Boiler Pressure 80·5 lbs.

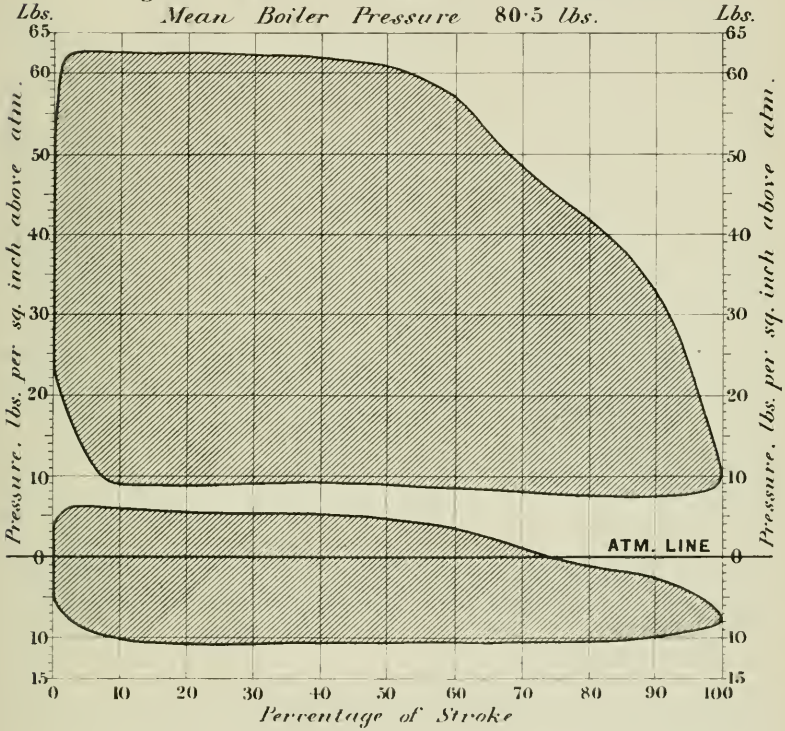
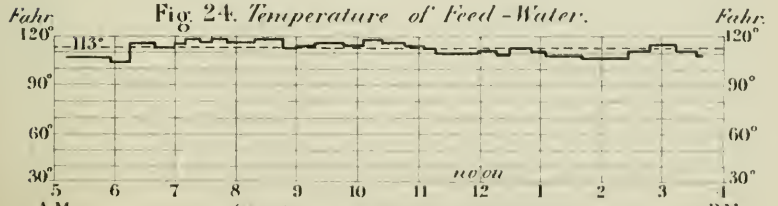


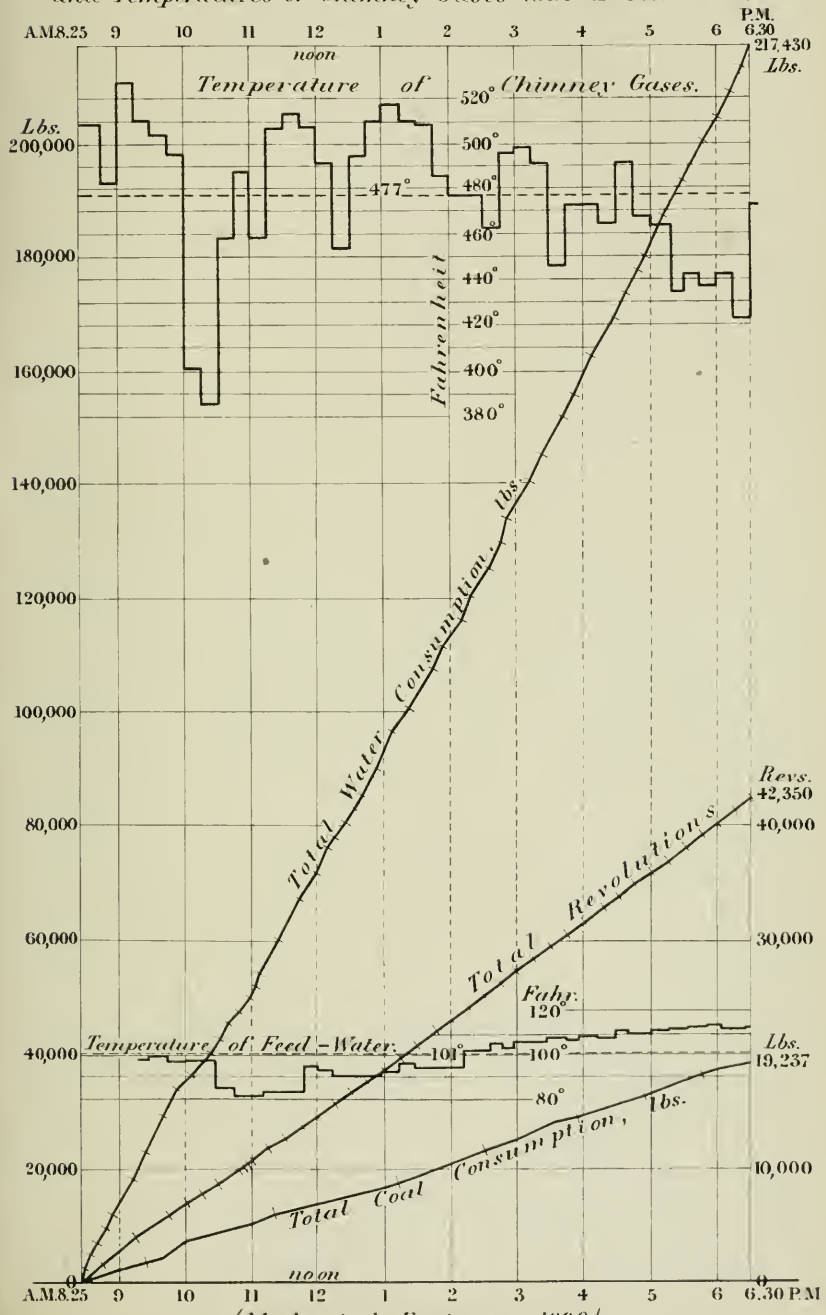
Fig. 24. *Temperature of Feed-Water.*



(Mechanical Engineers 1890)

Trial of the "Tartar."

Fig. 25. *Total Coal, Water, and Revolutions; and Temperatures of Chimney Gases and of Feed-Water.*



(Mechanical Engineers 1890)

MARINE-ENGINE TRIALS.

Plate 38.

"*Tartar.*" Fig. 26. *Total Indicated Horse-Power.*

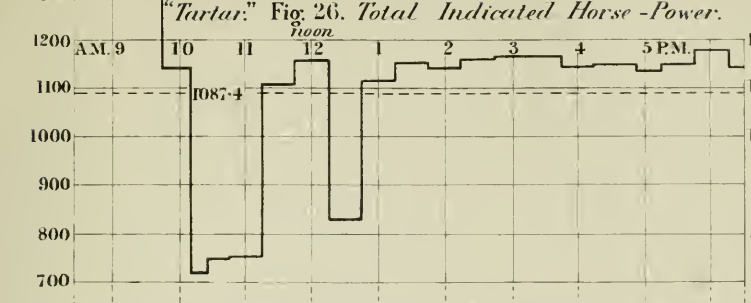


Fig. 27. *Boiler Pressure above atmosphere.*

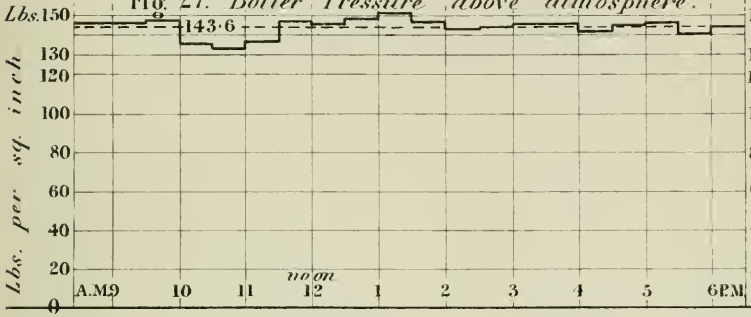


Fig. 28. *Revolutions per minute.*

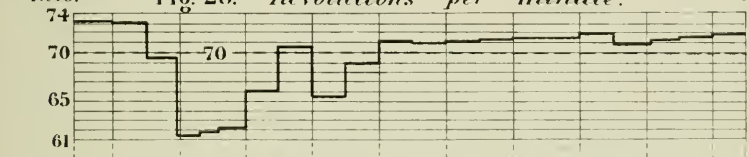
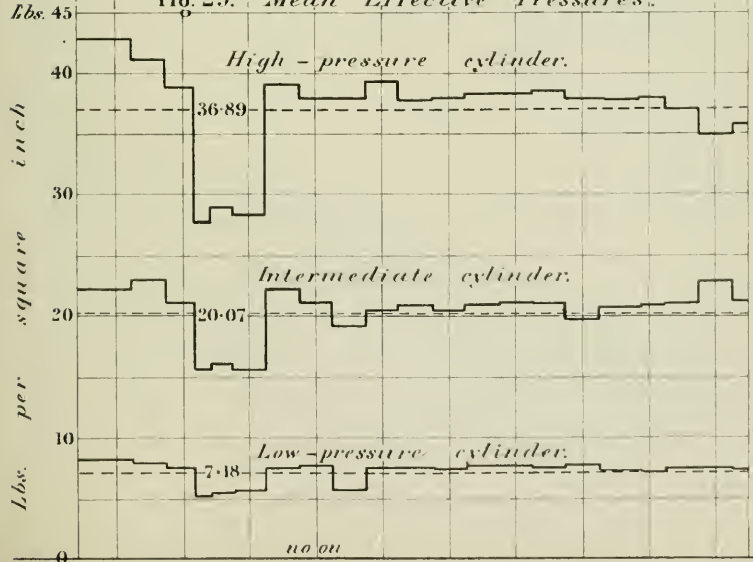


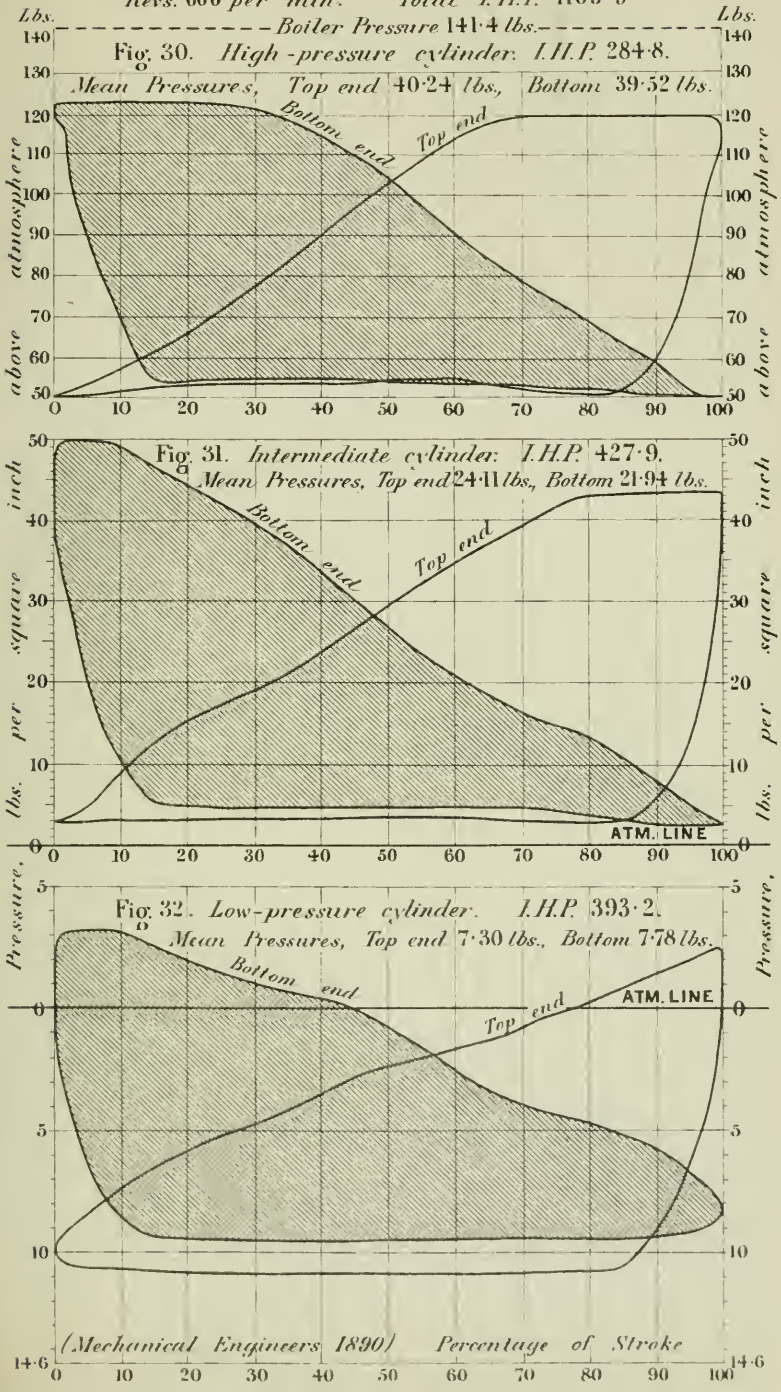
Fig. 29. *Mean Effective Pressures.*



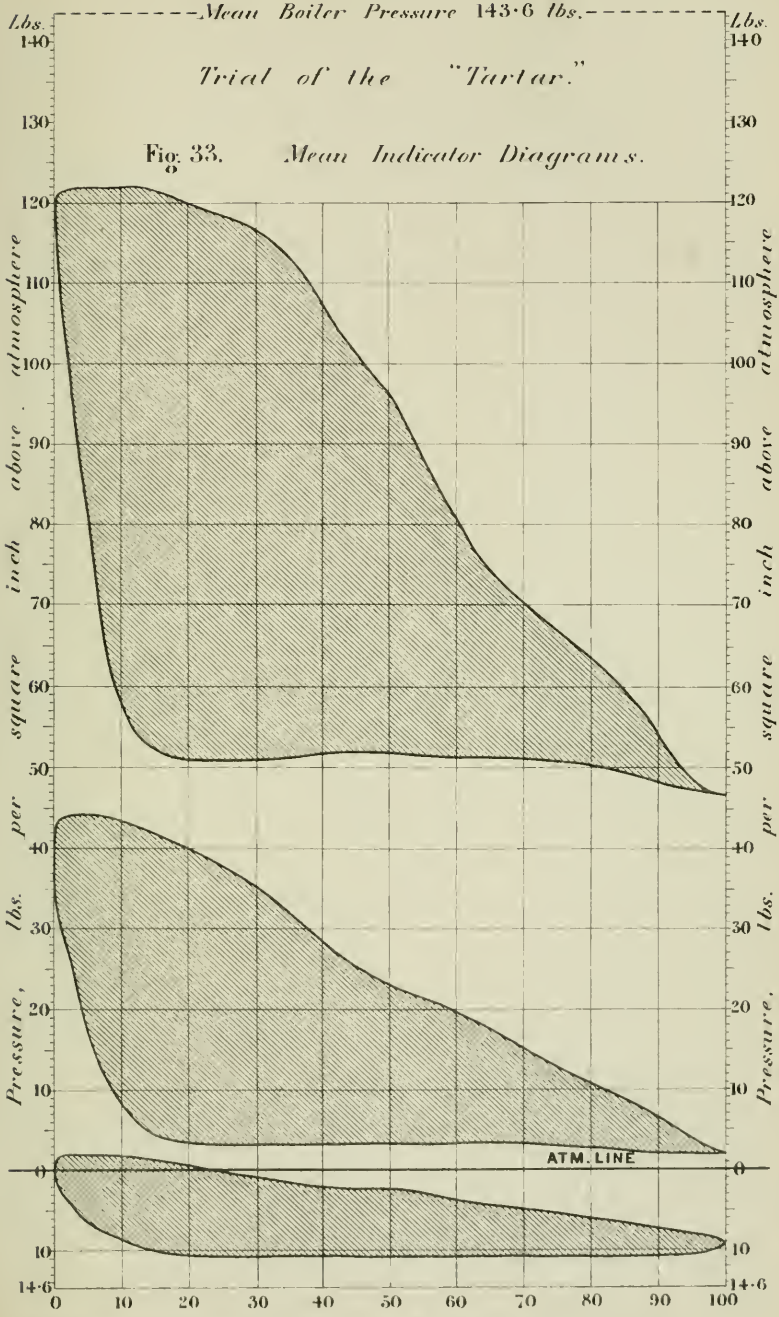
(*Mechanical Engineers 1890*)

"Tartar" Indicator Diagrams. Set 7.

Revs. 66·0 per min. Total I.H.P. 1105·9

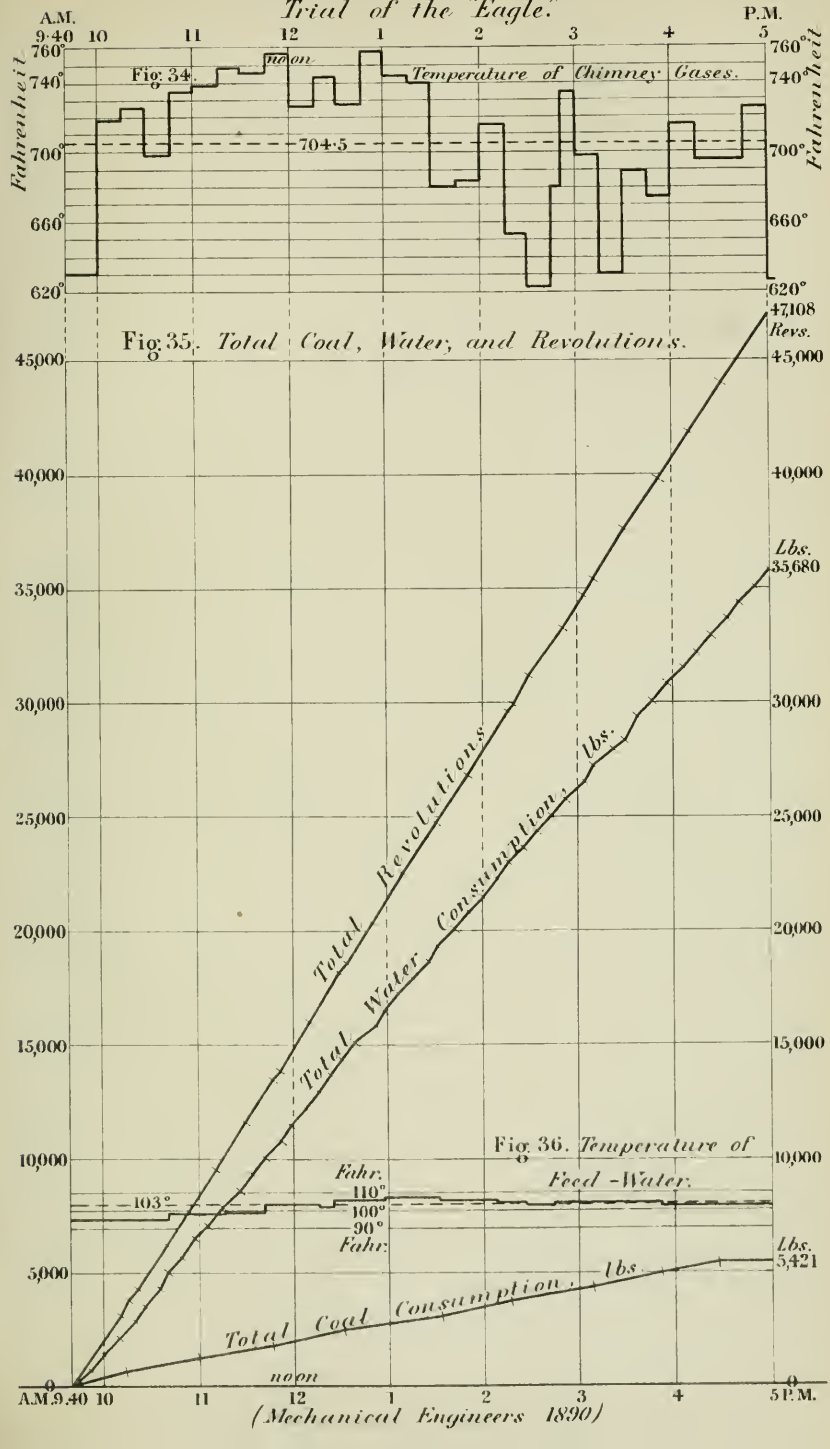


(Mechanical Engineers 1890)


Mean Boiler Pressure 143·6 lbs.
Trial of the "Tartar."
Fig. 33. Mean Indicator Diagrams.
lbs. above atmosphere
Pressure, lbs. per square inch
ATM. LINE
14·6
0 10 20 30 40 50 60 70 80 90 100
Percentage of Stroke

(Mechanical Engineers 1890)

Trial of the "Eagle."



(Mechanical Engineers 1890)

"*Eagle.*" Fig. 37. *Total Indicated Horse-Power.*

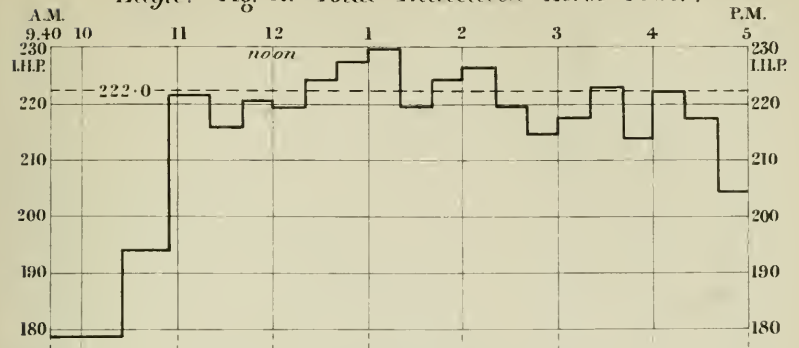


Fig. 38. *Revolutions per minute.*

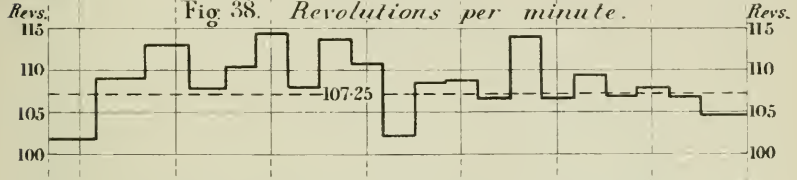


Fig. 39. *Boiler Pressure above atmosphere.*

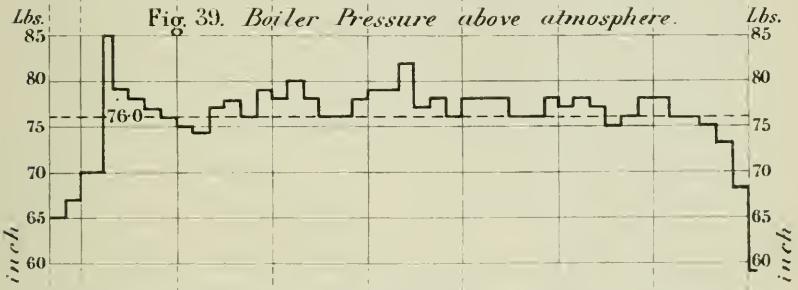
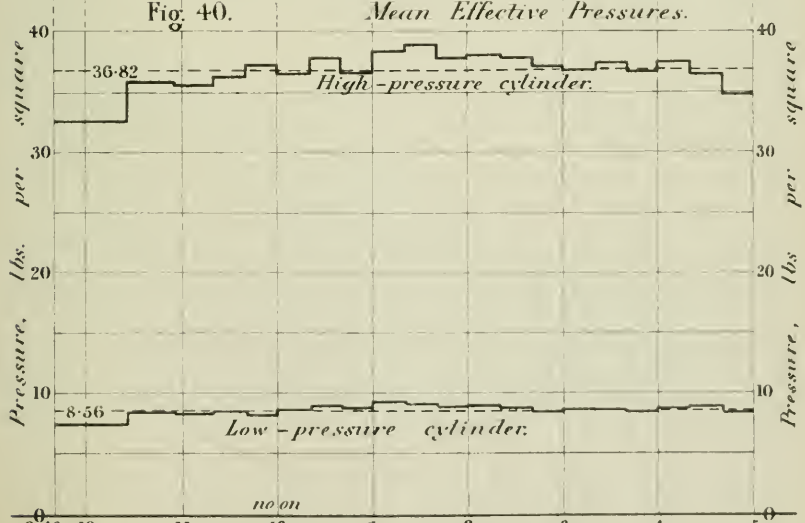


Fig. 40. *Mean Effective Pressures.*



"Eagle" Indicator Diagrams, Set 15.

Revs. 106·7 *per min. Total I.H.P.* 217·4.

Fig. 41. *High-pressure cylinder. I.H.P.* 119·7.

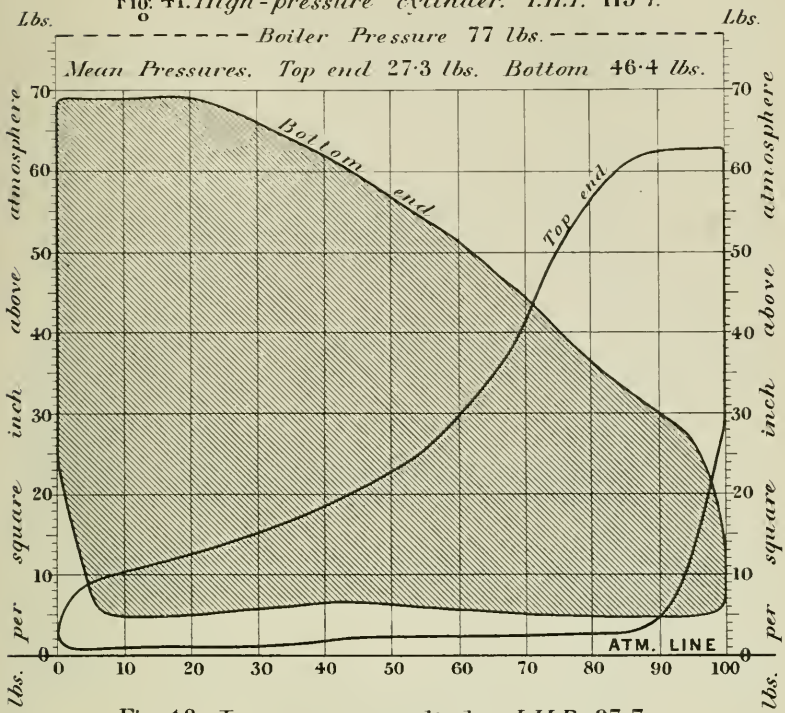
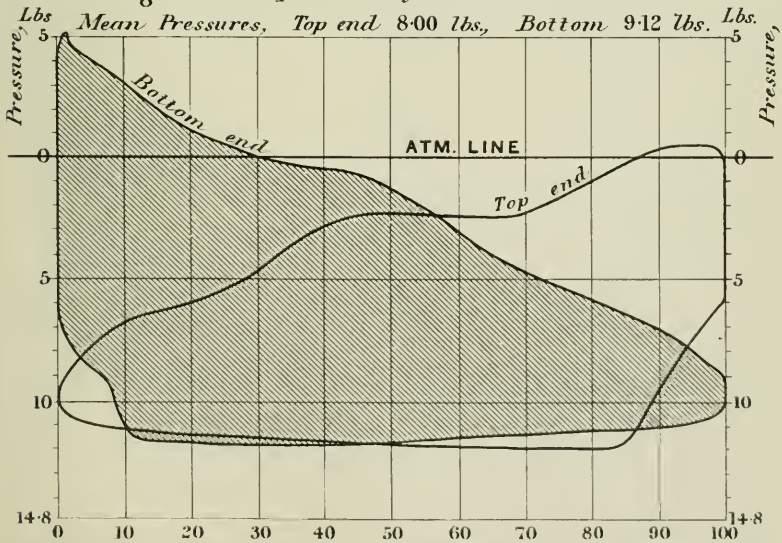

Lbs.
Boiler Pressure 77 lbs.
Mean Pressures. Top end 27·3 lbs. Bottom 46·4 lbs.
Bottom end
Top end
ATM. LINE
lbs. per square inch above atmosphere
0 10 20 30 40 50 60 70 80 90 100

Fig. 42. *Low-pressure cylinder. I.H.P.* 97·7.



(Mechanical Engineers 1890) *Percentage of Stroke*

MARINE-ENGINE TRIALS.

Cylinders of the "Fusi Yama."

Fig. 43. *Vertical Section.*

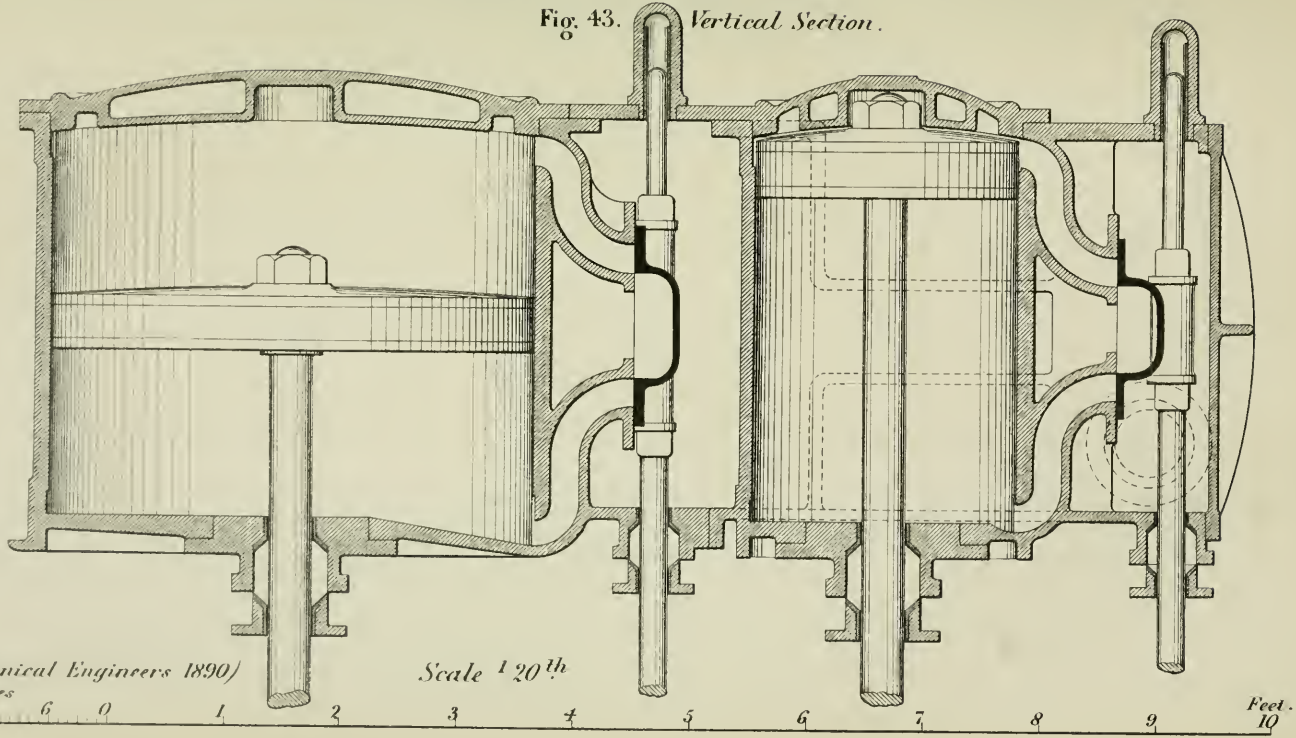
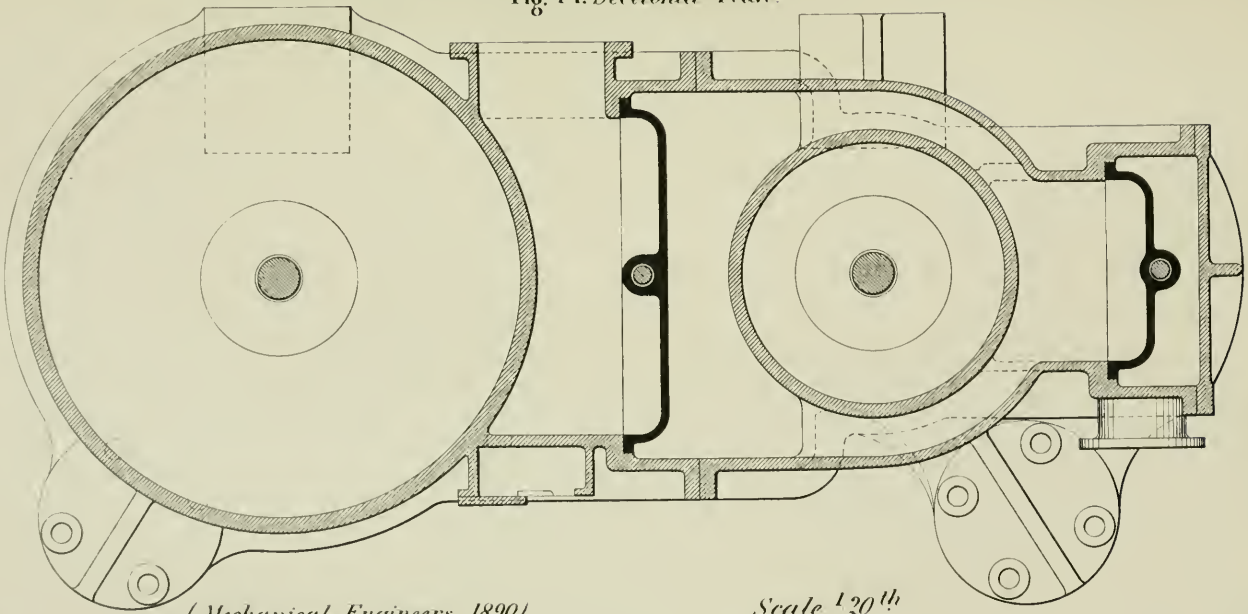


Plate 104.

MARINE-ENGINE TRIALS.

Cylinders of the "Fusi Yama".

Fig. 44. *Sectional Plan.*



(Mechanical Engineers 1890)

Scale $\frac{1}{20}$*th*

Inches 12 6 0 1 2 3 4 5 6 7 8 9 Feet 10

Plate 105.

Boiler of the "Fusi Yama".

Fig. 45.
Transverse Section.

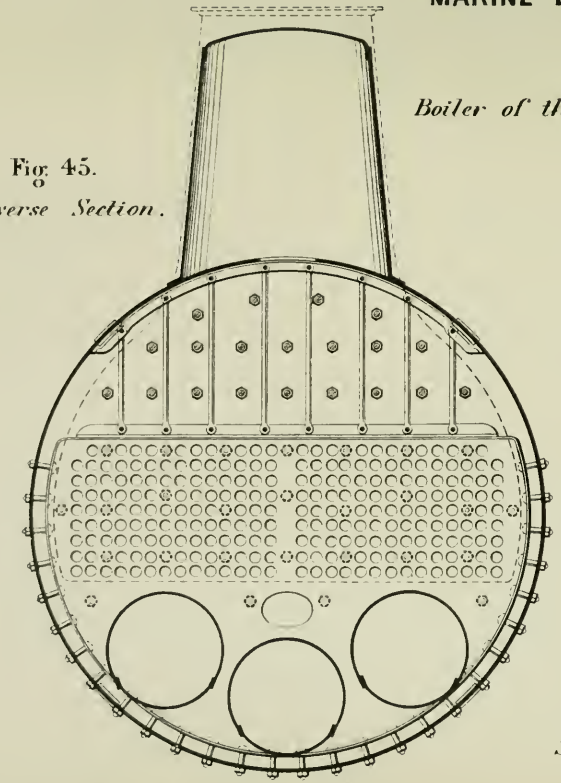
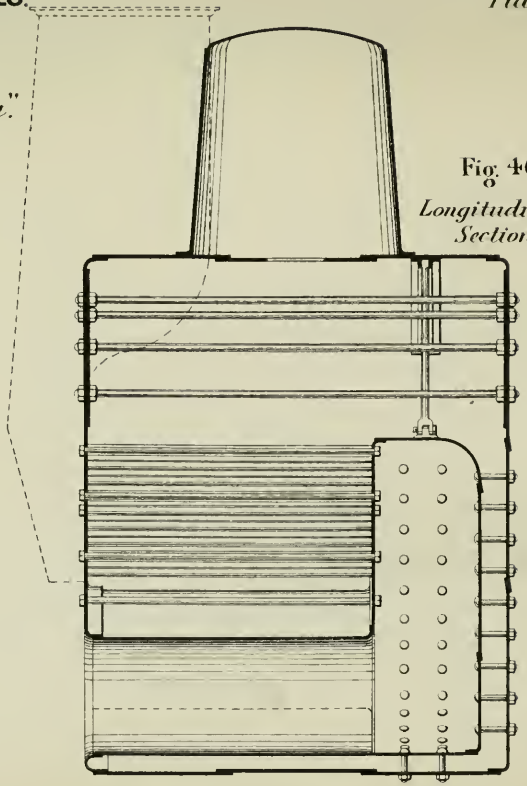


Fig. 46.
Longitudinal Section.



Scale 1/60th

Inches 12 0 5 10 15 20 Feet.

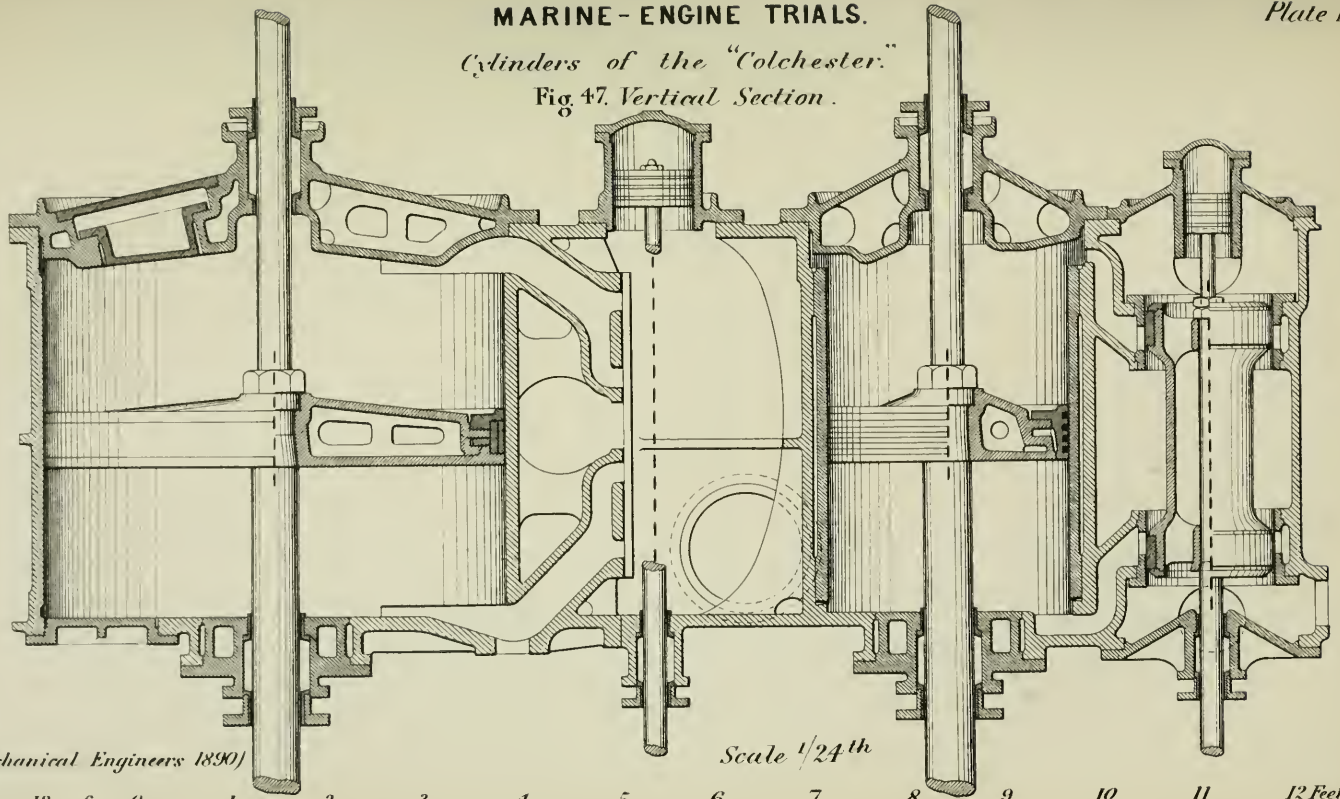
(Mechanical Engineers 1890)

Plate 106.

MARINE-ENGINE TRIALS.

Cylinders of the "Colchester."

Fig. 47. *Vertical Section.*

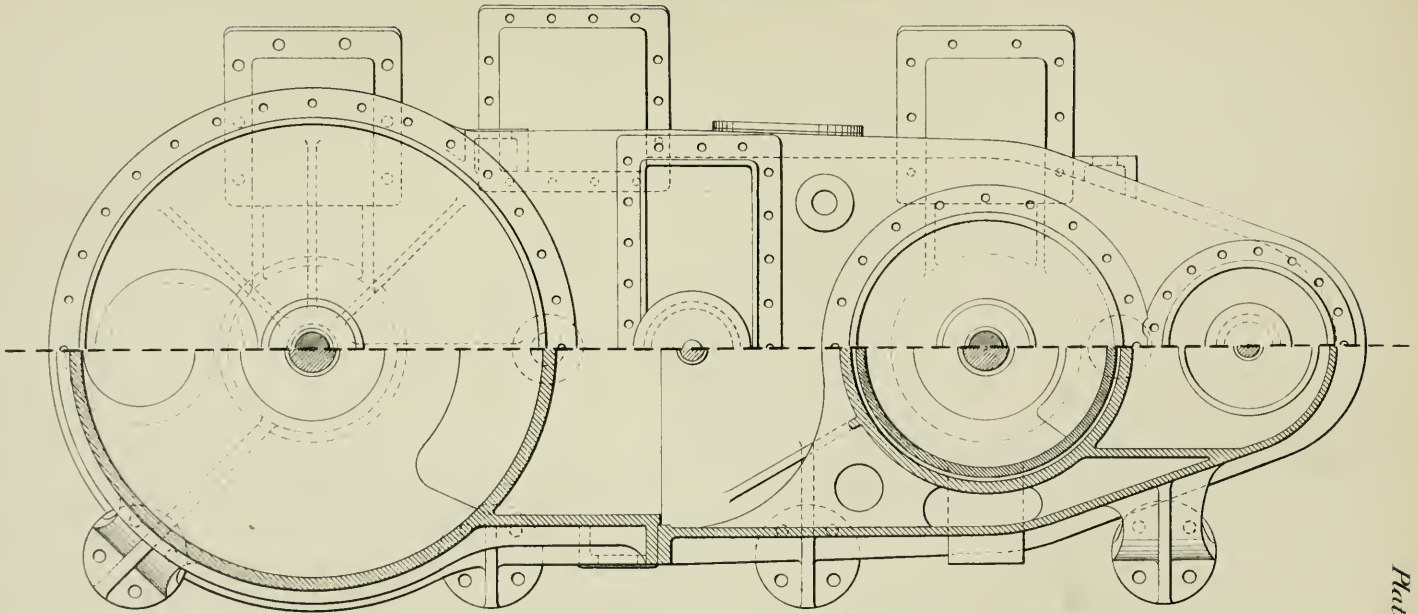


(*Mechanical Engineers* 1890)

Plate 107.

Cylinders of the "Colchester."

Fig. 48. *Sectional Plan.*



(Mechanical Engineers 1890)

Scale 1/24th

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet.

Plate 108.

Boilers of the "Colchester."

Fig. 49.
End Elevation and Transverse Section.

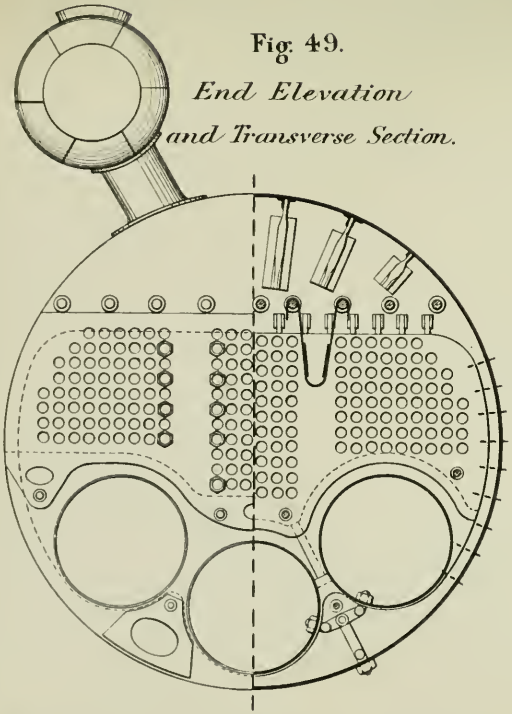
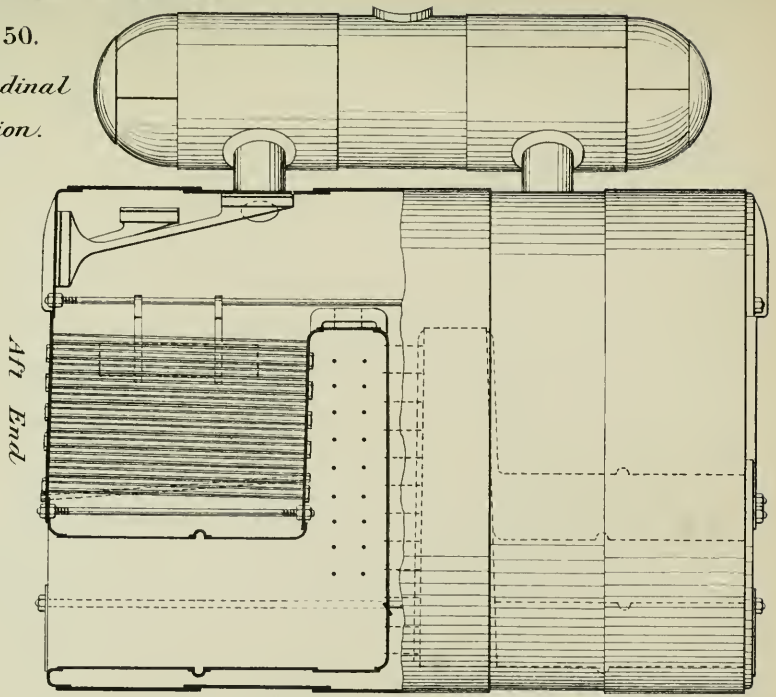


Fig. 50.
Longitudinal Section.



Scale 1/60th

Inches 12 6 0 — 5 — 10 — 15 — 20 Feet.

(Mechanical Engineers 1890)

High-Pressure Cylinder of the "Tartar."

Fig. 51. *Sectional Plan.*

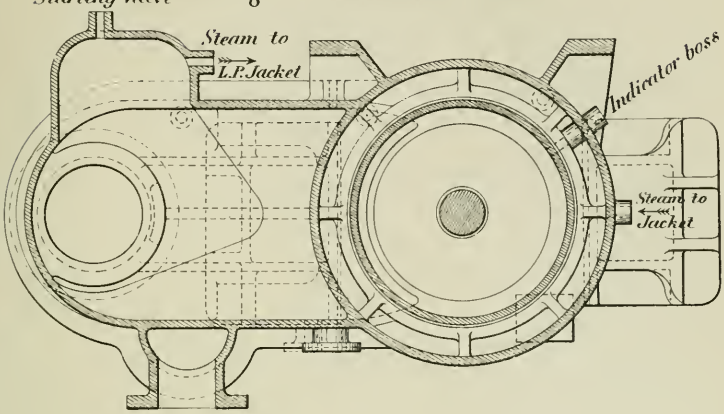
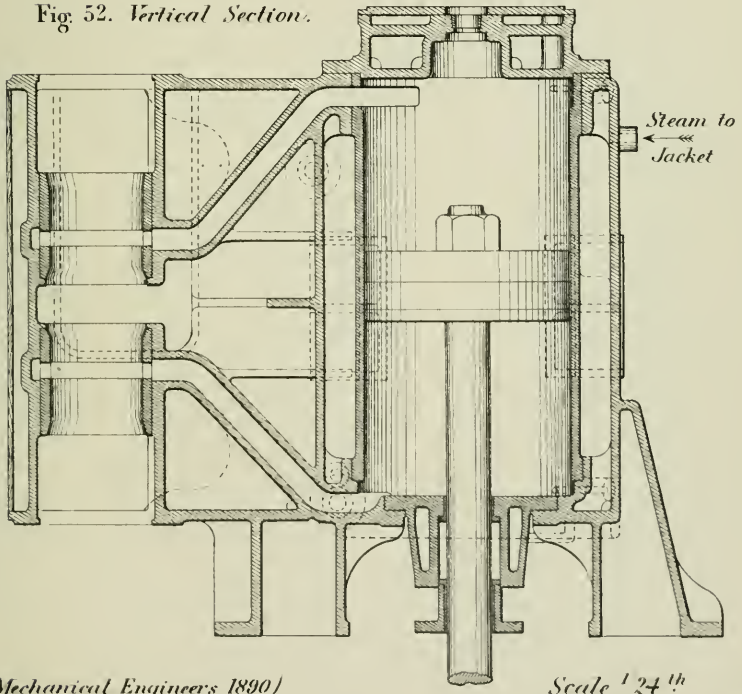


Fig. 52. *Vertical Section.*



(Mechanical Engineers 1890) *Scale 1/24th*

Inches 12 6 0 1 2 3 4 5 6 7 Feet.

Intermediate Cylinder of the "Tartar."

Fig. 53. *Sectional Plan.*

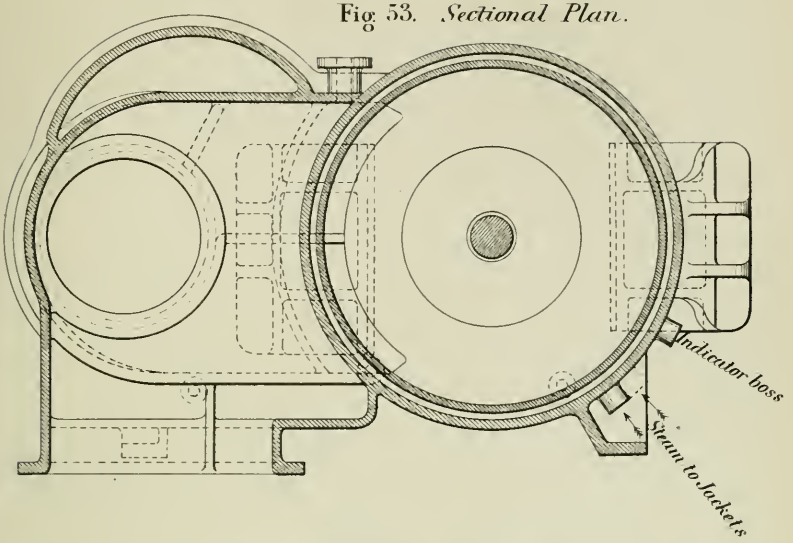
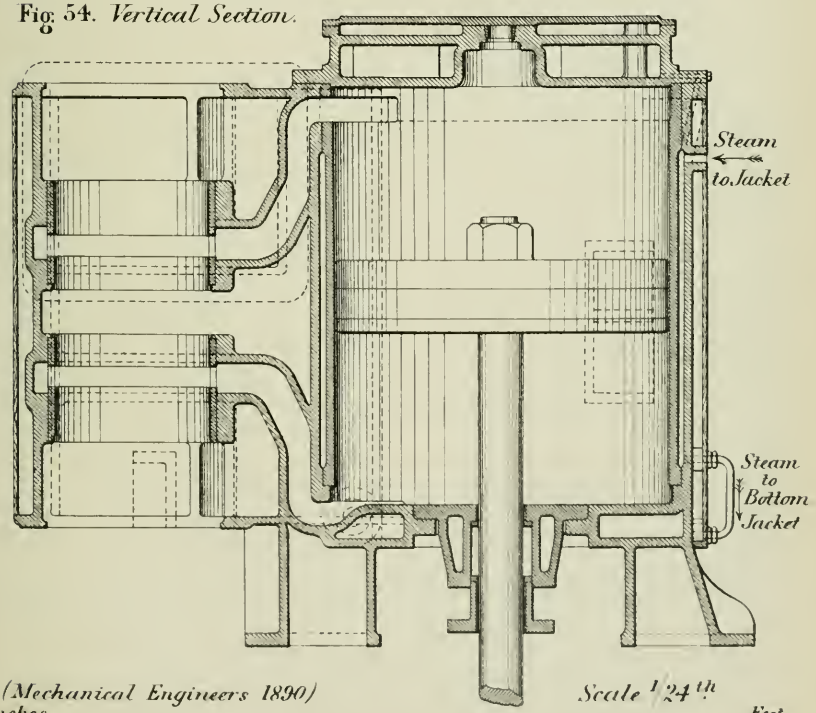


Fig. 54. *Vertical Section.*



(Mechanical Engineers 1890) *Scale 1/24th*

Low-Pressure Cylinder of the "Tartar."

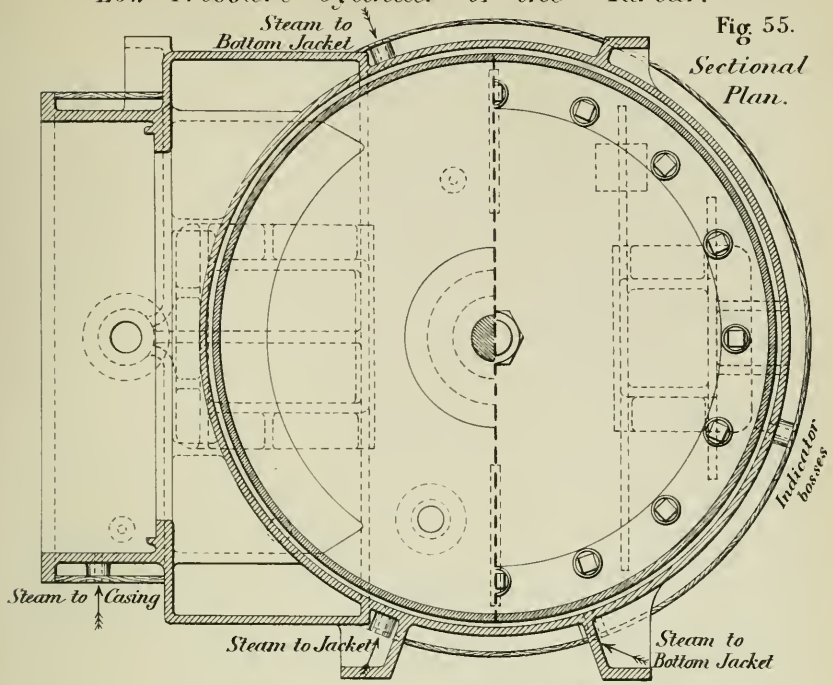


Fig. 55. *Sectional Plan.*

Fig. 56. *Vertical Section.*

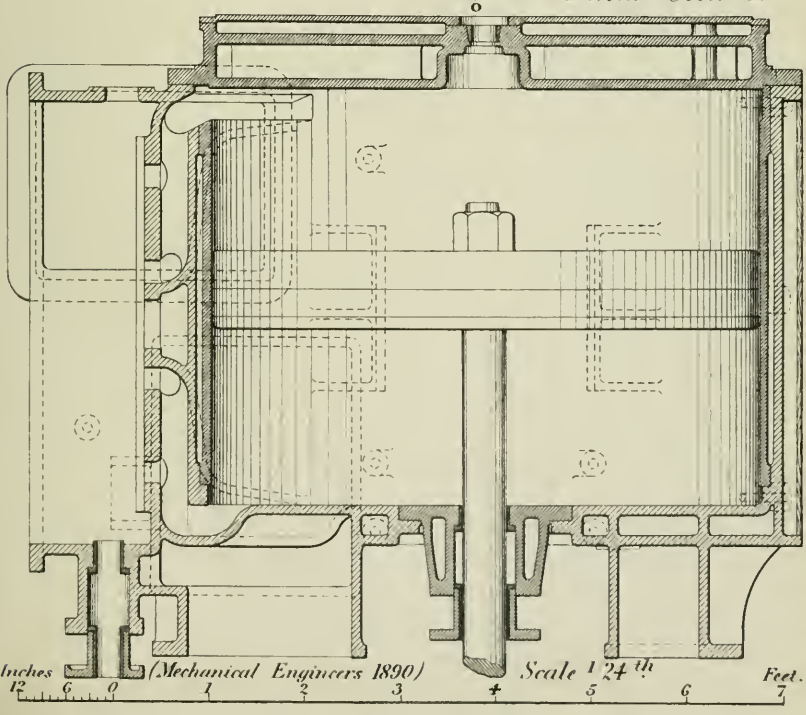


Plate 113.

Boilers of the "Tartar."

Fig. 57. *Transverse Section and End Elevation.*

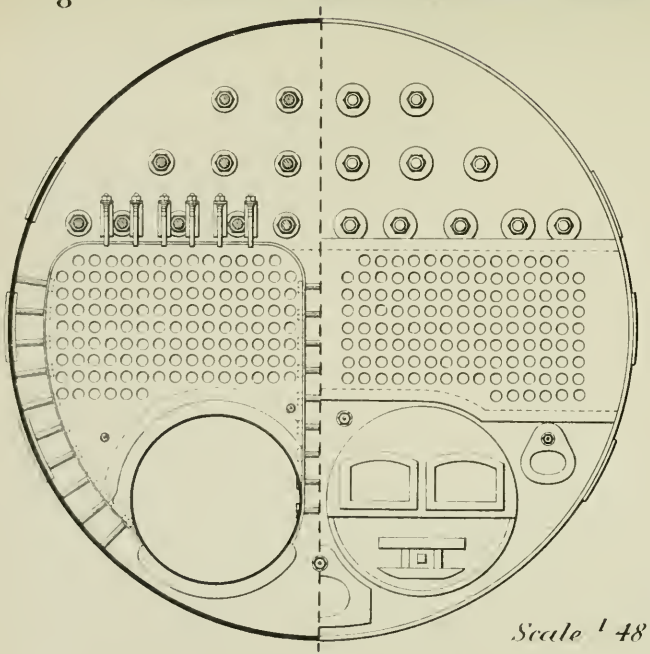
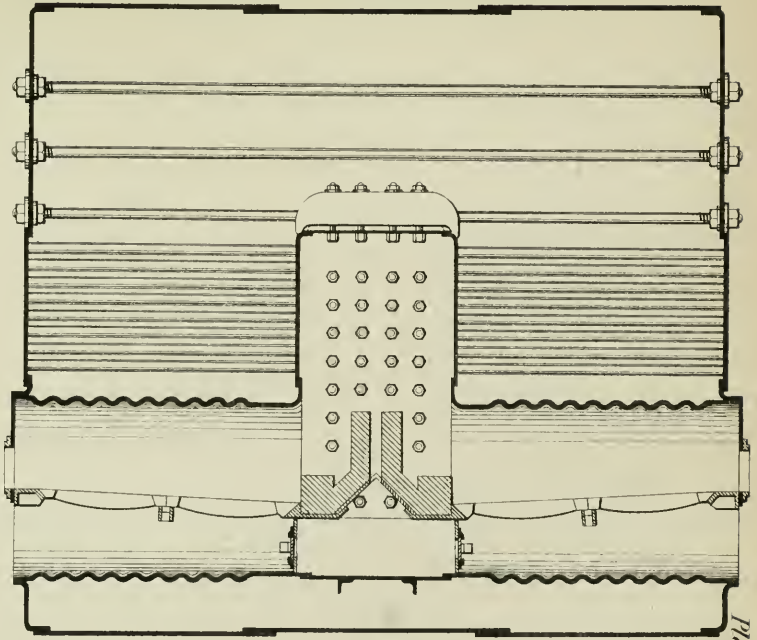


Fig. 58. *Longitudinal Section.*



Scale 1/48th

Inches 12 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

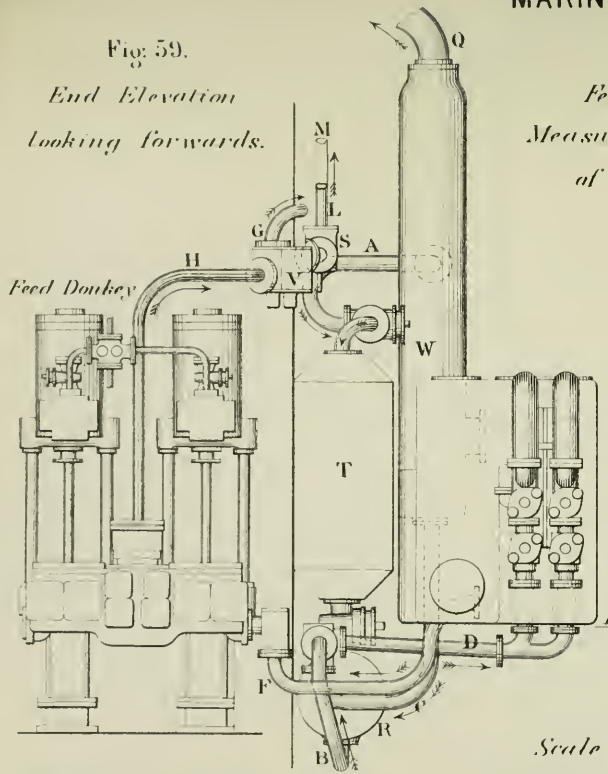
(Mechanical Engineers 1890)

Plate 113.

Fig: 59.

End Elevation

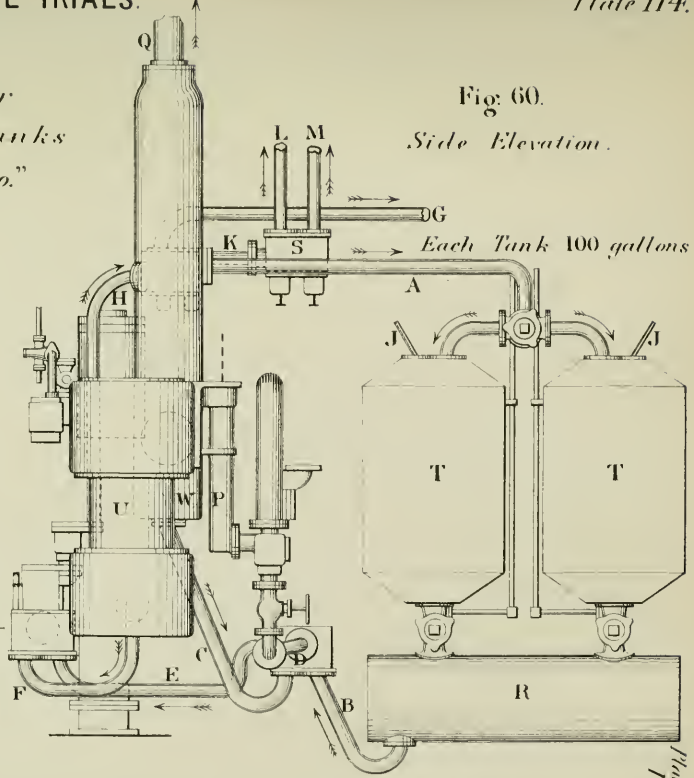
looking forwards.



Feed-Water Measuring Tanks of "Olympo."

Fig: 60.

Side Elevation.



Scale 1/40th

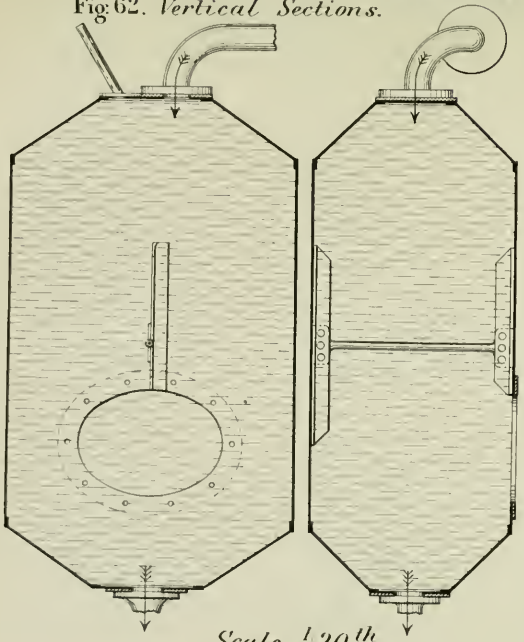
Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Mechanical Engineers 1890)

Plate 114.

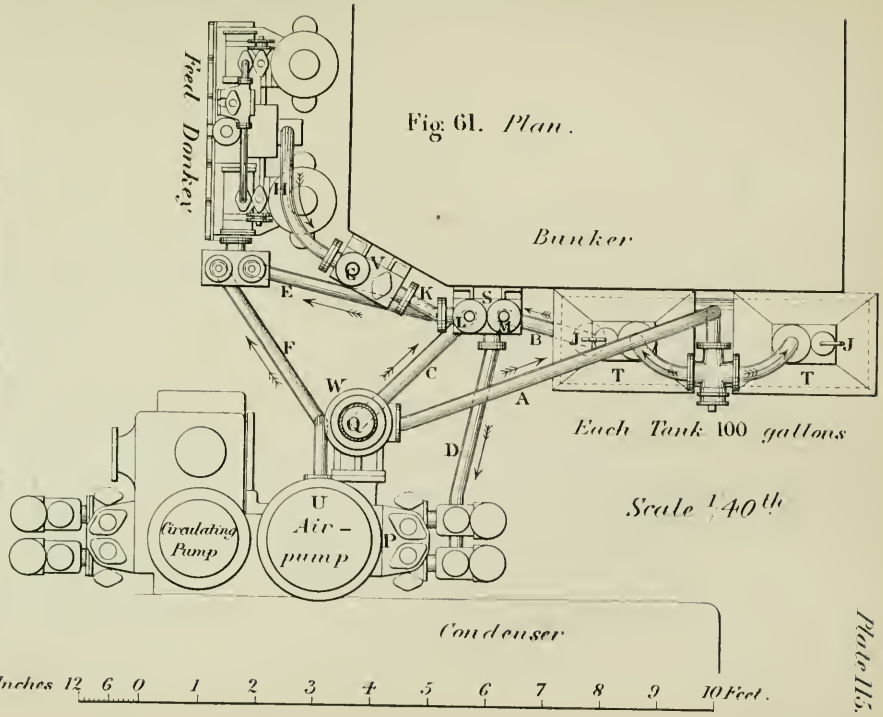
Feed-Water Measuring Tanks of "Olympo."

Fig. 62. *Vertical Sections.*



Scale 1/20th

Fig. 61. *Plan.*



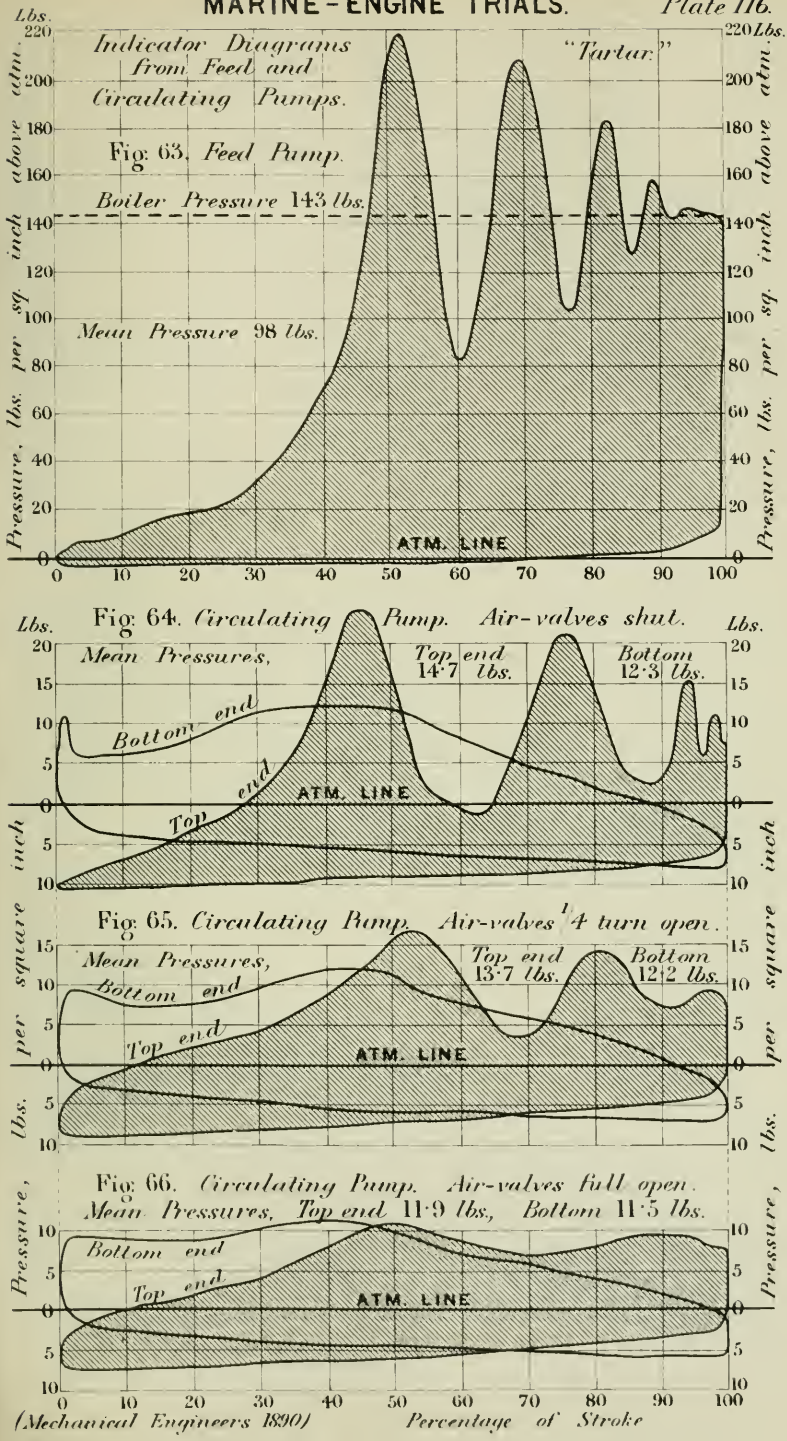

Indicator Diagrams from Feed and Circulating Pumps.
"Tartar."
Fig: 63. Feed Pump.
Boiler Pressure 143 lbs.
Mean Pressure 98 lbs.
ATM. LINE
Lbs. Pressure, lbs. per sq. inch above atm.
Fig: 64. Circulating Pump. Air-valves shut.
Mean Pressures,
Top end 14·7 lbs.
Bottom 12·3 lbs.
Bottom end
Top end
ATM. LINE
Fig: 65. Circulating Pump. Air-valves 1/4 turn open.
Mean Pressures,
Top end 13·7 lbs.
Bottom 12·2 lbs.
Bottom end
Top end
ATM. LINE
Fig: 66. Circulating Pump. Air-valves full open.
Mean Pressures, Top end 11·9 lbs., Bottom 11·5 lbs.
Bottom end
Top end
ATM. LINE
0 10 20 30 40 50 60 70 80 90 100
(Mechanical Engineers 1890) Percentage of Stroke

Fig. 67.

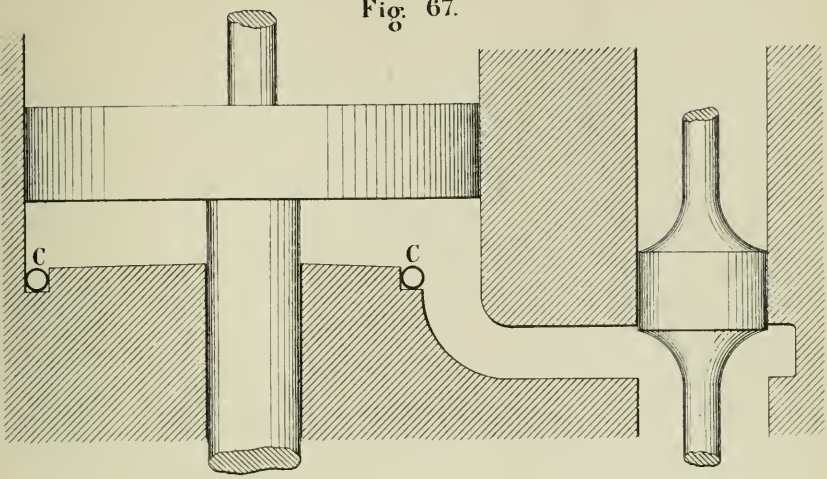


Fig. 68. *Indicator diagram with water in cylinder.*

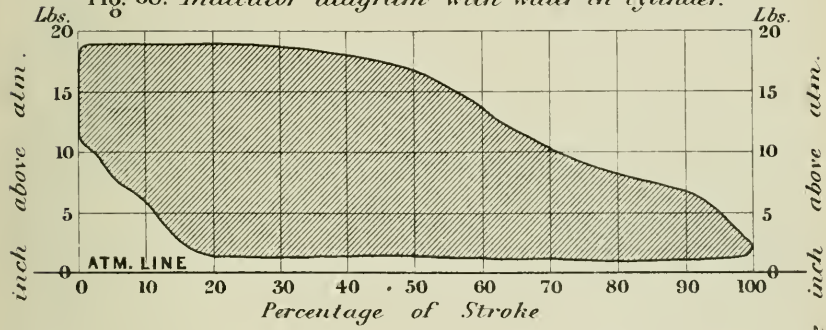
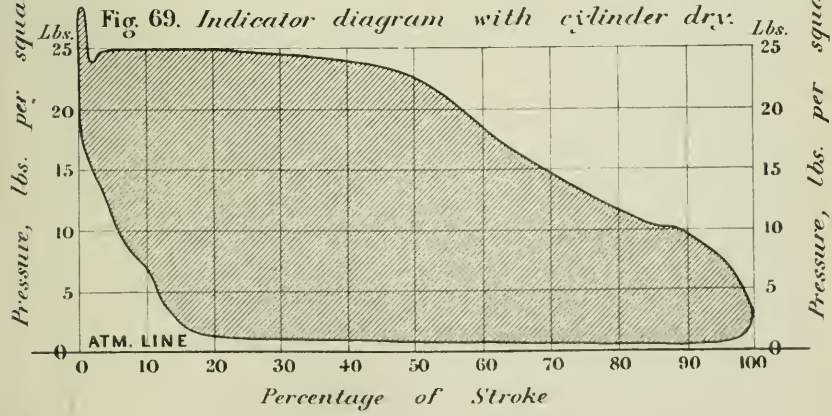


Fig. 69. *Indicator diagram with cylinder dry.*



(Mechanical Engineers 1890)

Institution of Mechanical Engineers.

PROCEEDINGS.

July 1890.

The Summer Meeting of the Institution was held in Sheffield, commencing on Tuesday, 29th July 1890, at Ten o'clock a.m.; Joseph Tomlinson, Esq., President, in the chair.

The President and Council and Members were received in the large Hall of Firth College, by the Mayor, J. B. Jackson, Esq., the Master Cutler, S. G. Richardson, Esq., and other members of the Reception Committee.

The Mayor said that, on behalf of the town of Sheffield, he had great pleasure in offering to the President, Council, and Members of the Institution a very hearty welcome upon the occasion of their visit to the town; and he trusted that their short stay would be alike pleasurable and profitable, and would result in benefit to mechanical engineering, for the advancement of which the Institution had been established. Since the last meeting of the Institution in Sheffield in 1861, twenty-nine years ago, immense strides had been made in the mechanical arts. It was not his purpose to review the great developments which had taken place; but he would content himself with saying that whatever had been required of his townsmen for carrying out those changes had been duly responded to by them, and they had upon all occasions been equal to any demands which had been made upon them. Should still further advancement take place, as he trusted would be the case in the future, he was confident that, if it could only be shown that there was a reasonable probability of a fair amount of remuneration from the venture, there was still sufficient capital, energy, and skill to supply anything that might be required in the progress of mechanical engineering. In the

preparation of the programme for the entertainment of the Members, the Reception Committee had followed the good old maxim of "business first and pleasure afterwards." After the first three days had been devoted to the reading and discussion of papers, and the visits to various engineering works and manufactories and other establishments in the town and neighbourhood, the fourth day would be spent in the two pleasure excursions which had been arranged as a conclusion to the Meeting. On behalf of his fellow townsmen he could only say they considered it an honour that Sheffield should have been selected by the Institution as the place of meeting for this year; and he was sure that nothing would be wanting on the part of the Reception Committee and their friends to render the visit of the Institution of Mechanical Engineers as successful and agreeable as possible.

He had now great pleasure in calling upon Professor Ripper as President of the local society of Engineers, to read an address of welcome from the society.

Professor RIPPER presented the following address:—

"At a meeting of the Sheffield Society of Engineers, a local society for the promotion of engineering science, held on Monday, 21st July 1890, it was unanimously resolved that this Society offers a hearty welcome to the Institution of Mechanical Engineers on the occasion of their visit to Sheffield, and trusts that the visit will be a pleasant and successful one. The Society further desires to record its sense of the valuable services which the members of the Institution have rendered to the country during the past forty-three years, in increasing the resources of our manufacturing and commercial industries, and in promoting and encouraging original research of a practical character; and the Society trusts that the Institution will long continue to record, for the benefit of their fellow engineers throughout the world, the results of their valuable experience."

Signed on behalf of the Society,

WILLIAM RIPPER, *President.*

PERRY HILL, *Secretary.*

The President desired in the name of the Institution to thank the Mayor, the Master Cutler, and the other members of the Reception Committee, for the kindness they had displayed during the time they had been engaged in arranging for the present Meeting. As it was twenty-nine years since the Institution had visited Sheffield, it had occurred to the Council that it was high time another visit should be paid to a town of such importance and so largely connected with mechanical engineering. It was gratifying to know that such cordial efforts had been made on all sides to render the Meeting a success. He also thanked Professor Ripper for the address which he had presented as President of the Sheffield Society of Engineers.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following sixty-five candidates were found to be duly elected :—

MEMBERS.

Arthur Harold Abbott, . .	Calcutta.
John Unwin Askham, . . .	Sheffield.
Philip Unwin Askham, . . .	Sheffield.
John W. Aston, ...	Birmingham.
Edward Turner Atkinson, . .	London.
George Bain, ...	Cairo.
Sir Benjamin Baker, K.C.M.G., .	London.
Alexander Bertram, . . .	Wigan.
Charles Henry Bingham, . .	Sheffield.
Robert Booth, ...	London.
Thomas Brogden, ...	Scarborough.
Robert Brown, ...	Northampton.
Henry Clifton Carver, . .	Manchester.
Edward Thomas Cleathero, . .	London.

ALFRED DICKINSON, . . . Wednesbury.
HUGH SHAW DUNN, . . . Kilmarnock.
Lt.-Colonel THOMAS ENGLISH, . . Jarrow.
JOHN ESSON, ... Aberdeen.
GEORGE GASKELL EXTON, . . London.
WILLIAM GADD, ... Limerick.
ROBERT HOLT, ... Liverpool.
WILLIAM PROCTER HOLT, . . Sheffield.
EDWARD THOMAS HUMPHRIES, . . Pershore.
JOHN WILLIAM JOHNSON, . . Moscow.
MORLAIS GLASFRYN JONES, . . Manchester.
JAMES PERCY KNIGHT, . . . Brighton.
ARTHUR JOHN LAST, . . . London.
LEONARD GEORGE LAURIE, . . Newport, Mon.
JOHN MACHRAY LEDINGHAM, . . Woolwich.
ROBERT RAMSBOTTOM LISTER, . . Manchester.
WILLIAM MAXWELL MACBRAIR, . Sheffield.
JOSEPH MACKAY, ... Bangkok.
FRANK HERBERT MARSHALL, . . Middlesbrough.
FRANCIS SANDERS MORRIS, . . London.
HENRY ADOLPHUS MÜLLER, . . Calcutta.
PERCY NEWTON, ... Buenos Aires.
WILLIAM OCKENDON, . . . Sheffield.
WESTON ALCOCK PERRY, . . . Birmingham.
JAMES RICHARD POWELL, . . Cardiff.
WILLIAM HENRY PREECE, . . London.
CHARLES HENRY PUGH, . . . Birmingham.
FREDERICK ARTHUR ROBINSON, . . London.
SYDNEY JESSOP ROBINSON, . . Sheffield.
CHRISTER PETER SANDBERG, . . London.
FREDERICK MCCLURE SCOTT, . . Liverpool.
AMBROSE SHARDLOW, . . . Sheffield.
WALDEMAR STUTZER, . . . Alexandrov, Russia.
ARTHUR TITLEY, ... Birmingham.
JOHN TRAIL, ... Swansea.
HENRY WALKER, ... Newcastle-on-Tyne.

John Wild, ...	Oldham.
Robert James Wilson, . . .	Cordoba, Arg. Rep.
Charles Aston Winder, . .	Sheffield.

ASSOCIATES.

Sidney Jennings, ...	London.
William McGillivray, . . .	Sheffield.
Samuel Newton Meggitt, . .	Sheffield.
John Taylor, ...	London.

GRADUATES.

Alexander Alderson, . . .	Lincoln.
Robert Percy Brousson, . .	London.
Arthur Brunel Chatwood, . .	Bolton.
Albert Davidson, ...	Sheffield.
Frank Garrett, Jun., . . .	Leiston.
John Philipson, Jun., . . .	Newcastle-on-Tyne.
Herbert Raffaelle Saxelby, .	Glasgow.
Alexander Cowan Wilson, . .	Leeds.

The following Papers were then read and discussed :—

On Steel Rails, considered Chemically and Mechanically; by Mr. Christer P. Sandberg, of London.

On recent improvements in the Mechanical Engineering of Coal Mines; by Mr. Emerson Bainbridge, of Sheffield.

At Half past One o'clock the Meeting was adjourned to the following morning.

The Adjourned Meeting was held in the large Hall of Firth College, Sheffield, on Wednesday, 30th July 1890, at Ten o'clock a.m.; Joseph Tomlinson, Esq., President, in the chair.

The following Papers were read and discussed :—

Description of the Parkgate Iron and Steel Works; by Mr. CHARLES J. STODDART, Managing Director.

Description of the Loomis process of making Gas for Fuel; by Mr. R. N. OAKMAN, JUN., of London.

Description of the Sheffield Water Works; by Mr. EDWARD M. EATON, Engineer.

The three remaining Papers announced for reading and discussion were adjourned to subsequent meetings.

The PRESIDENT proposed the following Votes of Thanks, which were passed with applause :—

To the Council of Firth College, for their kindness in offering the accommodation of the College for holding the Meeting of this Institution, and for the facilities obligingly afforded in connection therewith.

To the Reception Committee—and especially to the Mayor as Chairman, the Master Cutler as Vice-Chairman, the Honorary Treasurer Mr. Robert A. Hadfield, and the Honorary Secretaries Professor William Ripper and Mr. R. Heber Radford—for the admirable arrangements they have so hospitably made for welcoming the Institution in Sheffield, and for enhancing the enjoyment of the Excursions they have so handsomely planned for the Members.

To the Proprietors of the various Engineering and Manufacturing Works and other Establishments opened to the inspection of the Members, for their kindness in affording facilities for the visit in connection with the Meeting.

To the Master Cutler, for his courtesy in granting the use of the Cutlers' Hall for the Dinner of the Institution.

To the Chairman and Directors of the Manchester Sheffield and Lincolnshire Railway, for their kindness in granting special facilities for the Excursions over their line.

The Meeting then terminated at a Quarter before One o'clock. The attendance was 277 Members and 77 Visitors.

ON STEEL RAILS, CONSIDERED CHEMICALLY AND MECHANICALLY.

By Mr. CHRISTER P. SANDBERG, of London.

Under the two heads indicated in its title, the present paper will deal with the conclusions which were arrived at respecting Steel Rails in the discussion that took place at the International Railway Congress held in Paris last autumn.

I. Steel Rails considered Chemically.

Safety and Durability.—As regards the safety and durability of steel rails, the general conclusion at the congress was that the rails should be as hard as is consistent with safety. Now hardness can be produced either mechanically or chemically or in both ways. By mechanical means it was no doubt obtained formerly in slow-running mills and with hammered blooms, and was largely the cause of the early Bessemer steel rails wearing so well. But at the present time, with the direct process of making steel and with quick-running mills, mechanical hardening has been largely done away with; and hardness produced by chemical means has to be relied on, which is not in favour of the safety of the rail. Then the question arises, what elements should be present in the steel to give it hardness, and what proportions of each are desirable for different conditions. The congress did not fix upon any definite chemical composition, but merely came to the general conclusion that the hard rail not only wears the best, but is also the safest. The latter is news to many besides the author, although this is the experience in France and Switzerland and particularly in Russia. From the evidence of these three countries it would look as if the hard rails are the best to resist crushing, and are also the best for safety, inasmuch as their tensile strength is not imperilled by the hardness of the steel.

In a diagram accompanying Mr. Werchovsky's report to the congress, upon tests made on the Russian State Railways with best rails, good rails, brittle rails, and soft rails, the average chemical composition and tensile tests are given as follows :—

Description of Steel Rails.	Best.	Good.	Brittle.	Soft.	Russian.	German.	English and French.
Carbon . . per cent.	0·28	0 28	0·25	0·21	0·22	0·25	0·36
Manganese . per cent.	0·67	0·60	0·54	0·74	0·53	0·52	0·61
Silicon . . per cent.	0·24	0·15	0·11	0·05	0·11	0·16	0·11
Phosphorus . per cent.	0·11	0·11	0·18	0·19	0·18	0·12	0·09
Tensile Strength { kilos. per sq. mm.	66	64	60	52	56	61	66
Tensile Strength { tons per sq. inch.	42	41	38	33	36	39	42
Elongation . per cent.	19	19	20	20	19	19	18
Contraction of area . . per cent.	36	43	47	53	45	44	40

The three columns indicating Russian rails, German rails, and English and French rails, are compiled from old times, as Russia has not imported any foreign rails for the last twelve years, and rail-making has much changed since then. It may further be stated that the English rails are the best, and the Russian the worst, because in the latter the percentage of phosphorus is so high as to constitute what was called "phosphor steel" when made some fifteen years ago.

As for the tensile tests, they tell very little; for the soft rails broke at only 33 tons per square inch, instead of the 41 tons for the good rails; while the brittle rails gave almost the same tensile strength as the good rails, and even more elongation and contraction. Could the transverse test under a falling ball have been substituted instead of these three slow and costly tensile tests, it would have discriminated better the merits of safe or brittle rails.

After the Russian experience gained by analyzing rails taken up from the road, which had given good and bad results in actual work, the imperial commission appointed to test the rails is stated by Mr. Werchovsky to be now working in the converse direction, that is, making rails of the three different chemical compositions, and laying them down on the road and testing them under the traffic.

Favourable effect of Silicon.—The high percentage of silicon, 0·24 per cent. in the steel rails in the first column giving the best results, is the striking feature in the foregoing analysis. Generally it is thought that, if phosphorus is as high as 0·11 to 0·15 per cent., silicon must be low, as well as carbon, if the rails are not to prove brittle under the traffic. This may explain the general fear of silicon, as shown by engineers specifying only 0·06 per cent. of silicon for rails, even where phosphorus is low. This fear arises from their making no difference between steel requiring maximum tensile strength, as for bridge and ship plates, where durability under wear is not needed, and steel for rails, where this is the first essential and tensile strength is of secondary importance. Some silicon is necessary, in order to produce sound steel; and its benefit is considered by the author to arise from its affinity for oxygen, whereby it has the effect of reducing the oxide of iron floating on the liquid steel after the sudden blowing in the converter. It first forms silica, which then takes up more oxide of iron and forms silicate of iron or slag, which floats on the top of the metal in casting, and absorbs all the carbonic oxide gas as it rises, thus making the metal very quiet in the mould, and the ingots almost as flat on the top as if they had been planed. It consequently renders steel castings solid, as is well known in steel foundries, where 0·25 per cent. of silicon is the usual proportion for obtaining a solid casting. In the absence of silicon, and with carbon as the hardener, the oxide of iron with the carbon in the steel forms carbonic oxide gas, which boils the metal before escaping, and causes bubbles and a spongy top in the ingots. These bubbles are to a certain extent squeezed together afterwards in the rolling, but never

so as to form such a sound mass as if the casting were solid and free from them.

In the wearing of rails made of these two different kinds of steel, the silicon steel rail is solid and does not peel or laminate. The low carbon steel rail, containing less than 0·30 per cent. of carbon, becomes deformed, spread out, and crushed at the rail ends, and as it wears it peels off in thin scales, arising from an unsound or spongy ingot. Even when the carbon is as high as 0·40 to 0·50 per cent., a tolerably solid ingot cannot be obtained without silicon to the extent of at least 0·10 per cent.; and this percentage of silicon is therefore what the author has generally preferred for steel rails.

Experiments on High Silicon Steel Rails.—As there would be more chance of success from high silicon steel rails made in England, where phosphorus does not amount to half as much as in Russia, the author determined to take the question up, and to make experiments in order to see whether there really was any advantage in silicon for producers and users alike. On communicating with some of the leading men of both classes in several countries, he found that their experiences were widely different. The question therefore could be solved only by impartial investigation and direct experiments, which were accordingly commenced. Preliminary results were soon obtained, which are embodied in Table 1 appended (pages 322–3), showing chemical and mechanical tests. These were so far satisfactory, and from them the three following conclusions may be drawn:—

1. That a heavy steel rail, containing silicon up to 0·30 per cent. and the same amount of carbon, will stand any ordinary transverse test under a falling weight, up to say one ton falling 15 feet, midway between bearings 3 feet apart, provided the phosphorus is low, say under 0·07 per cent., and the manganese not too high. So the large amount of silicon does not seem to make the rail brittle, judging at least from these experiments.

2. That silicon up to 0·30 per cent. makes no visible difference in the hardness, so far as is shown by deflection under the falling weight or by impact or by tensile tests: the different results obtained being altogether dependent upon the proportion of carbon.

3. That silicon at 0·20 per cent. and upwards gives a sound ingot with a clean solid top, which rolls out into a rail with fewer defects than steel that contains only 0·06 per cent. of silicon, other ingredients being the same.

These earlier conclusions however required to be verified on a larger scale, having been tested so far by only a few single casts. A second series of a greater number of experiments were therefore made. The results in Table 2 (pages 324–6) are of a very different character from those in Table 1. From Nos. 1 to 15 of the chemical and mechanical tests in Table 2, the three following final conclusions are drawn:—

1st. By silicon up to 0·30 per cent. with carbon up to 0·30 or 0·40 per cent. the steel is neither hardened nor made brittle, and its strength is diminished in only such a small degree as not to imperil the safety of the rail, judging at least from a severe transverse impact test under a falling weight.

2nd. Silicon up to 0·20 or 0·30 per cent. certainly makes the steel quiet in casting, and free from small honeycombs or blisters; but in cooling from a fluid to a solid state it draws or shrinks much more than rail-steel containing only 0·10 per cent. of silicon, or less. The ingots, particularly large ones weighing a ton or more, are very liable in cooling to form a hole in the centre, which, when the ingot is rolled into rails, produces in the web or neck of the rail a seam not welded, as in test 11 of Table 2. From this fault a fracture of the rail may occur, and may be more disastrous than the peeling off in thin scales that arises from small blisters round the exterior surface of the ingot, which are formed when silicon is low. Thus high silicon steel can be used with safety in small ingots only, say of not more than half a ton. This explains the favourable results obtained with such steel in Russia, where probably small ingots are made for single rails only. In the large ingots of say one ton and upwards, for three or four rails as now rolled in England, more than 0·10 to 0·15 per cent. of silicon should not be aimed at, on account of the greater shrinkage produced thereby. The danger is therefore seen of fixing upon one composition as applicable to all makes of steel; and it is clear that care should

be taken in considering all the reasons before changing the practice. For instance, what will do for working small ingots in Russia and elsewhere, will not answer for large ingots as worked in England; and engineers would do well to leave the silicon question to the rail-maker, who in every case has the best experience of what suits his own requirements and those of the users generally. These results respecting shrinkage arising from silicon in steel agree with those given by Mr. Hadfield in his recent paper on alloys of iron and silicon (Iron and Steel Institute Journal, 1889 II, page 222); but as he experimented with ten times as large a percentage of silicon as in the case now under consideration, and not directly upon rails, the present experiments may be a better guide to the solution of the question of silicon in rail-steel.

3rd. As for a high percentage of silicon in basic steel, it has the same effect on shrinkage as in the Bessemer steel. But it should be remembered that silicon, added in the form of hæmatite pig-iron before the manganese is put in the ladle, is what prevents the re-phosphorization of the basic steel; and that without this valuable discovery, made by Mr. E. Windsor Richards when manager of Messrs. Bolckow and Vaughan's steel works at Middlesbrough, the basic steel rail would have died a natural death. However there is only just enough silicon added to take up the oxide of iron and protect the steel from re-phosphorization, and none or very little is left in the steel, say from a mere trace up to only 0·06 per cent.; and as there would be the same shrinkage in large ingots as with high silicon Bessemer steel, no experiments with basic steel have been found necessary.

Thus both for Bessemer and for basic steel, the presence of such a high percentage of silicon as is used in Russia, say 0·25 per cent., seems not applicable in England, unless small ingots were reverted to: which again would be a disadvantage, because the larger ingots mean more work put upon the steel, and therefore the better are the rails. The ingots experimented with in Table 2 weighed 28 to 30 cwts. each, enough for four rails of 80 lbs. per yard and 30 feet long; while those in Table 1 were much smaller, and consequently presented no apparent shrinkage and no holes in the centre. In

Bessemer steel rails therefore the author sees no reason to interfere with the silicon, and he recommends leaving it altogether to the option of the maker. For tires and axles, which are made from smaller ingots than rails, it might be a decided advantage to use up to 0·20 per cent. of silicon, in order to get them solid; and he believes this is done by the makers when they have no chemical composition stipulated.

There seems to be no difficulty in obtaining a high percentage of carbon—0·40 to 0·45 per cent.—by the basic process as well and to the same extent as by the Bessemer, though with somewhat less silicon in the basic steel; and this should annul the general condemnation of the basic rails that was pronounced at the congress, simply because they were made by the basic process.

Hardness dependent on Carbon and Phosphorus.—As regards the hardness of steel rails, it would appear from these experiments that silicon is of no consequence, everything depending upon the percentage of carbon and phosphorus. Being a pupil of Eggertz, the author brought with him to this country in 1860 from the School of Mines at Fahlun his method for estimating carbon in iron and steel, and made it known in the Chemical News of 30 May 1863, pages 254–6; and nowhere has this quick and simple method been more applied than in Sheffield. There have been three excellent papers * on the hardening of steel, which are of great value as a guide in this respect: the first was in 1879 by Professor Richard Åkerman of Stockholm; the second was in 1883 and 1885 by Sir Frederick Abel, read to this Institution; and the third was last year by Professor Roberts-Austen. The changes produced by the hardening, which practically commences with about 0·40 per cent. of carbon, are just what alter the quality of steel rails according to the manner of cooling them. The mode of cooling should be studied very carefully, and may be found to require covered hot banks, in order to obtain the most uniform result in the wearing of the rails.

* Iron and Steel Institute Journal, 1879 page 504. Proceedings of the Institution of Mechanical Engineers, 1883 page 56, and 1885 page 30. "Nature," 7 and 14 November 1889.

Increase in the hardness of steel rails was recommended at the congress by engineers from many different countries; but the author has still sufficient dread of the results which might follow from fractured rails to prevent his going to any extreme in that direction; and considering the great variety of conditions to which rails are subject, he would not attempt to prescribe any particular degree of hardness as being applicable to all countries. Where so many factors are involved, there are hardly two cases alike. In the manufacture it is necessary to consider the varying amount of all elements present in the steel worked in different districts, the section of rail employed, the mode of rolling adopted, and whether the straightening is done by cambering the rail while hot. The last is a very important operation, and the author is glad to find that the leading rail-makers in England have now followed his advice and adopted the hot cambering of the rail, in order to lessen the effect of the barbarous cold-straightening by presses. Then after the rail has been laid on the road there are questions of climate, drainage, ballast, sleepers, weight of rolling stock, speed, amount of traffic, &c., all of which must be taken into account, and their importance decided upon according to particular circumstances. At present the users of steel rails have nothing much to complain of; their safety is much greater than that of iron rails, their durability is at least three times as great, and their price is much lower. Why then overdo the hardness and thereby risk the safety? The greatest merit in an engineer as well as in a rail-maker is to know when to let well alone; and the author certainly intends to exercise this discretion, and will not let himself be led astray by any wonderful chemical composition of steel rails; otherwise, serious accidents may accrue, and then, to use a Sheffield rail-maker's expression, the services would be required not only of a chemist but of a druggist as well.

II. Steel Rails considered Mechanically.

Heavier and Harder Rails for Safety.—In his address at the last meeting of this Institution, the President paid the author the compliment of referring (page 197) to his efforts to improve the design of flange rails, and said:—"We in England have gone on increasing

the weight of the rail to meet the greater weight of engine, and have added sleepers in proportion until 2 feet 6 inches to 2 feet 8 inches is now their distance from centre to centre; but some of our foreign neighbours, notably the Germans, are still a long way behind us, notwithstanding they have equalled us in the weight to be carried on a pair of wheels." In 1886 the author gave a paper to the Institution of Civil Engineers * describing his first design of Goliath steel rail of flange section, Fig. 4, Plate 119, weighing 100 lbs. per yard; and in 1889 another on the use of heavier rails, arguing the necessity for a base-plate, Figs. 1 and 2, Plate 118. The only safe way to increase the hardness is to increase the weight of the rail at the same time, making it both heavier and harder; but to make it harder alone is to run a great risk of fractures, notwithstanding the strong temptation to try to obtain more wear or economy without increased outlay; and it is just here that the soundness of the theory adopted for the Goliath rail comes out. Heavier rails can be made harder with safety from fractures. It was this argument, added to the necessity of greater stability of the road, that induced the Belgian State Railway to make the first trial with the Goliath rail in 1886; and they have since laid ten to fifteen thousand tons yearly on their roads, amounting now to an aggregate of nearly fifty thousand tons. In Table 3 (page 327) is given a comparison between weight of engines and weight of rails shown at the Paris Exhibition last year; and it is interesting to find how all French railways have of late years increased the weight of their rails, the Paris Lyons and Mediterranean up to 94 lbs. per yard. The conclusion that in England there is light rolling stock on heavy rails, while on the Continent generally it is the opposite, is a clear argument for the necessity of introducing heavier rails on the Continent. But the most forcible argument is that the difference in price of old and new rails is so small. For instance, six months ago the price in England of old rails was £4 per ton, and now the price

* "On Rail Joints and Steel Rails;" Proceedings of the Institution of Civil Engineers, vol. lxxxiv, 1885-6, page 365. Stahl und Eisen 1886, pages 236 and 320. Revue universelle 1886, pages 226 and 286. "On the use of Heavier Rails for Safety and Economy in Railway Traffic;" Proceedings of the Institution of Civil Engineers, vol. xcv, 1888-9, page 354.

of new rails is only £5; thus four-fifths of the value can be realised after wearing them out, if bought and sold at a proper time. The Swedish Government Railways, for which the author is consulting engineer in regard to rails, have actually availed themselves of this favourable period for selling their old rails and getting new rails at the above prices. In fact nowadays the true economy for users of steel rails is to have plenty of metal in the rails, thereby saving cost of maintenance: just the reverse of what was the case twenty years ago, when steel was three times the price it is now.

A singular coincidence happened a few months ago. At the same time that it was decided at a railway conference at Rome in January last that "trains de luxe," corresponding with our trains provided with dining and sleeping cars, should be established between all great towns on the Continent, another congress was held at Düsseldorf, where one German State Railway authority declared that the rails were heavy enough and the roads good enough. But the "trains de luxe" mean heavier carriages, heavier engines, and greater speed, all of which can be put in operation in a short time; whereas to strengthen the road in proportion to this greater strain would take from ten to twenty years, and as yet no commencement has been made.

In Austria the Goliath rail, Fig. 5, Plate 119, has found more support; and the Nestor of iron and steel in that country, the venerable Professor Peter Tunner, writes that the simplest reasoning would be enough to uphold the necessity of the Goliath rail for heavy traffic, which to him is so clear and simple a matter that he cannot understand how anyone can doubt it. In an address delivered in Vienna on 7th December last, by Herr Von Hornbostel, before the Austrian Society of Engineers, the following remarks occur:—"In England there are many trains which have a speed of 52 to 68 miles an hour; in France and Belgium they can travel 50 to 56 miles an hour; while our fastest trains in Austria barely reach 40 miles an hour.* It is

* In Messrs. Foxwell and Farrer's book on "Express Trains, English and Foreign," the Austrian speed is given as 29 to 39 miles per hour exeluding stops, and 20 to 37 including stops. Their definition of express trains is 29 miles per hour for foreign railways and 40 for English, including stops.

easy to see then that we have much to learn from our neighbours. But the safety of the train must be preserved while the speed is being increased; and I claim that this question of safety prevents our increasing the speed, while the roads remain in their present condition. All railways running faster trains than in Austria have better roads. The English engineers lay their heavy rails in large chairs. The French trains run over 92 lbs. rails, and the sleepers are spaced closer than here. The Belgians have the Goliath rail, 106 lbs. per yard (53 kilos per metre). Our own rails have the following weights per yard :—

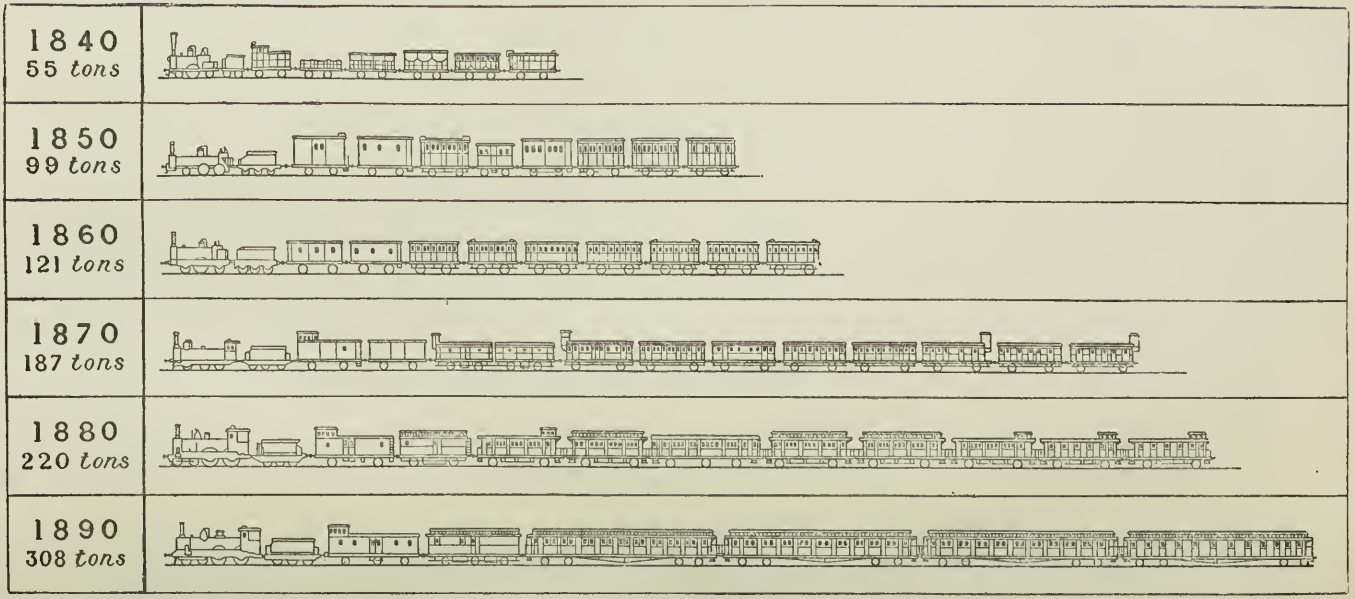
Royal State Railway	71 lbs. per yard.
State Railway	70½ ,,
King Ferdinand Northern Railway . .	70 ,,
Southern Railway	69½ ,,
North Western Railway	67 ,,

In the accompanying diagram (page 312) the growth of our express trains is shown; the weight given includes that of the locomotive and tender."

Thus in Austria engineers seem aware of the desirability of using heavier rails; and it seems astonishing, when French private railways have followed the example of the Belgian State Railways, that German State Railways should remain without heavier rails for their roads.

Flange Rail without base-plate.—As English railways rank first in respect to safety, economy of maintenance, and speed, they were naturally regarded at the Paris congress as the best for high speed and heavy traffic. Even the double-headed rails and chairs laid on half the railways in France, although the rails are somewhat old-fashioned, were considered superior to the flange rail. In England some flange rails have also been used in old days on branch lines with light traffic, but most of them have been replaced by rails of the double or bull-head form usual in this country. An interesting paper has this year been written in "L'Industrie moderne" by Mr. Flamache, engineer of the Belgium State Railways, balancing the pros and cons of the two plans; but he forgets that there is no choice, or at least very seldom, inasmuch as a change of system

Diagram showing Increase in Length of Trains on Austrian Railways, 1840 *to* 1890.



could hardly be carried out. For a heavily worked railway to exchange its flange rail for a double or bull-headed rail with chairs is almost an impossibility; therefore it is not a question of choice, as in constructing a new line. Hence even those, who in Paris recommended the English plan as the best, preferred themselves to strengthen their own lines by the adoption of heavier flange rails to correspond with their increased traffic. Every railway will have to keep to its own form of rail, whatever may be the opinion about the best.

Goliath Flange Rail with steel base-plate and steel key.—Then comes the question whether, by adopting heavier flange rails with steel base-plates of equal surface to the chair, a road cannot be made as good and strong as on the English plan. As to the cost, a small saving may be counted upon for the Goliath flange rail, Fig. 5, Plate 119, with large steel base-plates weighing 13 lbs. each, Figs. 1 and 2, Plate 118, which latter cost only two-thirds of the chairs. But, be that as it may, the main question whether as good and strong a road can be obtained will be answered by the Goliath rail already adopted on the Continent. There is also hope of a fair comparison in England from a trial of the Goliath flange rail with steel base-plates and steel keys, all made at the Barrow Steel Works; this trial is now being made on the Furness Railway, thanks to the managing director, Sir James Ramsden, and the engineer, Mr. Stileman. Hitherto the flange rail laid in England has had but a poor chance in competing with the double or bull-headed rail, because nowhere has it been of equal weight, nor has its section been of good form for fishing the joints, nor has it had a steel base-plate. America, where flange rails only are used, shows that plan of road to great advantage; for even admitting that their flange rails are weak, although they have lately increased their weight from 60 lbs. up to 80 lbs. per yard, their speed is quite as high as on the Continent of Europe, and their freight tariff is only half that of the English railways, and still they pay a dividend. There is ample room however for increasing the weight of their flange rails still further, even up to 100 lbs. per yard, before they reach the cost of the English lines, notwithstanding that the centres of the sleepers

are only 2 feet apart on the American roads, instead of $2\frac{1}{2}$ feet on the English.

While the author has no idea of introducing the flange rail on English lines, any trial of that plan in this country for the sake of comparison would greatly benefit both the foreign railways and the English steel-rail trade generally, if it could be proved that by means of the Goliath rail with base-plate as good and strong a road could be obtained as by the present English plan; for heavier flange rails would then necessarily be adopted abroad, wherever the traffic has grown beyond the capacity of the lines originally constructed with light flange rails, and would thus benefit all such railways and the rail trade.

Double-headed and Bull-head Rail with chairs.—In now briefly reviewing the improvement of rails and permanent way during the last thirty years, a just tribute cannot but be paid to our Member Mr. R. Price-Williams, for his valuable work in this direction. Thirty years ago the railways in England were laid with double-headed rails; but it was soon found that the chair wore the rail too much to be turned, so it was converted to the bull-head section, gradually increasing in weight up to 90 lbs. per yard. No doubt the increase will go on; and the author accordingly shows in Fig. 7, Plate 120, and the accompanying model, his joint for a 100 lbs. bull-headed rail, which he recommends for all railways having excessive traffic, such as those in and about London. The vibration complained of by residents in the neighbourhood of the Underground and other railways would be much remedied by a rail strong enough itself to carry the load, and so to distribute it over many more sleepers: instead of the present weaker rail, which bends under the load, and shakes the whole road bed and the neighbouring ground as well. Moreover the costly maintenance and frequent repair of the weak rail would thereby be much diminished, and the consequent saving would soon repay the small increased cost due to the increased weight of rail. With a good chair this rail would be regarded as the perfection of permanent way; and it is satisfactory to know that its adoption is under consideration on the District Underground Railway.

Development of Flange Rail.—As already pointed out, heavily worked railways having flange rails would prefer to strengthen their present section of rail, rather than change it for a different form. It may be well therefore to consider what the flange-rail road formerly was, what it now is, and what it might be. When the author came to this country thirty years ago to inspect flange rails for the Swedish Government, he made the improvement of the rail itself his special study. But he has since found out that he began improving at the wrong end, that is, from the top instead of from the bottom of the rail; and he is glad to have an opportunity here, as he had at the Paris congress, of correcting this error. The beginning ought to have been made at the base, by fixing the rail to the sleeper more firmly; instead of this, he began by improving the rail joint, as then the most apparently weak point. Iron rails were then used of a pear-shaped section, with which it was impossible to get any vertical stiffness in fishing with plain fish-plates; and the joint was therefore supported by a sleeper with a sole-plate. But as this acted like an anvil, the badly welded rail-ends soon became flattened and split like a broom. The sleeper was then taken away, and the joint was suspended between two sleepers. In order to obtain greater stiffness of the joint, the fishing angle had to be altered and the rail section to be re-constructed. As the result of his experiments the author published in 1870 his first series of standard sections for iron rails, giving a width of base equal to the height, and a fishing angle of 11° for both top and bottom edges of the fish-plate. On comparing the section shown in Fig. 6, Plate 120, of the former 80 lbs. iron rail with that of the present 100 lbs. Goliath steel rail, Fig. 5, Plate 119, designed with due regard to latest experience, it will be seen how little in reality is the difference in his design after these twenty years. When steel came into use for rails, it became necessary that the form of section should be so modified as to take advantage of the nature of the new material in rolling; and the author was led to publish in 1878 a further series of standard sections for steel rails, with the height slightly greater than the width of base, and with a fish-joint of either angular or deep section, the fishing angle being increased from 11° up to 15°, as shown in

Fig. 3, Plate 119. The fish-joints in the former series of standard sections for iron rails gave only one-third of the stiffness of the solid rail; but the new angular fish-joint, Plate 119, gave two-thirds, and the deep fish-joint, Fig. 7, Plate 120, gave stiffness equal to that of the rail itself. Both these later joints were tried on a large scale upon the Swedish State lines, and the one of angular section was there preferred to the deep joint, owing to the severity of the cold in winter. This has been the experience elsewhere as well: so that the angular fish is now the joint mostly used for flange rails, whereby notching of the rail flange is avoided. But the deep fish found preference in England with the bull-headed rail section, Fig. 7, Plate 120, and has proved a great boon for realising the present degree of perfection in obtaining a line of continuous stiffness. Great as is the advantage both to producers and to users of having standard rail sections, these are nevertheless not an unmixed benefit, as they naturally tend to check the free progress of science. The author's sections have however been rolled to the extent of several millions of tons, or in larger quantities than any others, simply because they have been designed with due regard both to producers and to users, and are available for adoption by anyone, being free from royalty or other charges.

American Flange Rail.—America has of late worked hard and in a very practical manner to establish fixed standard sections, by appointing a committee for the purpose; and their full report * just published will do a great deal of good to American engineers and railmakers. If the International Railway Congress in Europe would undertake such a task it would be of immense value. The main feature of the American standard rail sections is that the height is equal to the width of base, while in Europe the height is much greater than the width of base. This makes the sole-plate all the more needed in Europe; but the author is convinced that it will

* "Final Report of the Committee on the proper relation to each other of the Sections of Railway Wheels and Rails." Transactions of the American Society of Civil Engineers, vol. xxi, October 1889, page 223.

before long be needed in America as well, although their bogie system of rolling stock is a great advantage in saving their track.

Another feature of the American standard section of rail is a flatter top, say 12 inches radius, and a sharp upper corner of the head. There is even one enthusiastic advocate for an absolutely flat rail-head and cylindrical wheels. The 12-inch radius for the top may suit Europe as well; but even if any rail-head were made quite flat-topped, it would soon wear down to even less than a 12-inch radius, since the present conical tires worn to a rounded section could not all be converted in a moment into cylindrical wheels. The sharp upper corner of $\frac{1}{4}$ inch radius no doubt suits the American bogie vehicles; but as not half the rolling stock in Europe is yet fitted with bogies or radial axle-boxes, it seems better to round the top corner a little more, so as not to risk running off on the curves. The lower corner of the rail-head is rounded with 1-8th to 3-32nds of an inch radius in America. This corner the author now makes quite a sharp edge, as shown in Figs. 2 to 5, Plates 118 and 119, in order to get the full bearing for the fish-plate; and he finds there is not the slightest difficulty to the maker. With this improved bearing of the fish-plate, the rail joint with angular fish-plates, Figs. 3 to 5, can be made equal in strength to the solid rail, as in the specimens exhibited. The great difference in the head of the Goliath rail is that it is made both wider and thinner than in the American rails generally, and has vertical instead of sloping sides, whereby two objects are attained:—firstly, greater durability, because the thick narrow rail-heads have worn badly in consequence of their interior being less compact than the surface; and secondly, the wider rail-head approaching to the width of the wearing surface of the tire will give greater tractive power to the engine, and diminish or supersede the necessity of turning up both engine and carriage tires. The latest section of the Goliath rail is accordingly made with 3 inches width of head, for both flange and bull-head section, as shown in Figs. 5 and 7, Plates 119 and 120.

Base of Flange Rail, and fixing to sleeper.—In respect lastly to the most important part, namely the base of the flange rail

and the mode of fixing it to the sleeper, there is here a very great difference from the chair, and the author regrets that most engineers have made the same mistake as himself in not beginning earlier to strengthen this part of the road; for while the rail joint is certainly a weak part of the road, the base is the weakest, as regards both safety of gauge and economy of sleepers. Happily a stir is now at last beginning to be made in this matter upon the Continent. Valuable experiments on the stability of the rail both vertically and horizontally have been made by Mr. Brière, engineer of the Orleans Railway. Several voices besides the author's were heard at the Paris congress in favour of base-plates. Mr. Bemelmans, engineer of the Belgian State Railways, spoke strongly on the subject; and in reporting upon the pressure exerted on the rail by the rolling stock, he remarks that, with the heavy engines now used, each axle may carry 15 tons dead load or $7\frac{1}{2}$ tons per wheel, while this load in running might from various causes be momentarily even double, or 15 tons per wheel. On a curve he considers that, besides the vertical pressure of 15 tons, the horizontal pressure on the outer rail may be half as much; and he calculates that the pressure of the outer rail on the sleeper is as follows:—for the flange rail of the section used on the Northern Railway of France, weighing 86 lbs. per yard and laid direct on the sleepers without base-plate, 6·3 tons per square inch; for the Goliath rail of the section used on the Belgian State Railways, weighing 105 lbs. per yard and with base-plate, 1·0 ton per square inch; for the bull-head rail used on the London and North Western Railway, weighing 90 lbs. per yard and with chair, 0·3 ton per square inch. On a straight line he calculates the pressure on the sleeper in the same three cases to be:—on the Northern Railway of France 1·3 ton per square inch; on the Belgian State Railways 0·4 ton; and on the London and North Western Railway 0·16 ton per square inch. These figures explain why with a large traffic the sleepers, even of oak, where the rail is without base-plates, are literally cut under the rail base, and are early rejected, not because they are decayed, but because the pressure is too great and the fastenings of wood screws or spikes are not strong enough to hold the rails to the gauge. On

the Paris and Lyons Railway, Mr. Michel, engineer of the permanent way, has taken to base-plates: the need of which is also proved in his report at the congress on the lines carrying express trains. With sleepers of softer wood than oak, such as fir or cedar, how much more valuable will the base-plate be. No lengthened argument is wanted to show the necessity of the base-plate for flange rails; all that is needed is to use common sense, remembering that a flange rail with base 5 inches wide, the widest that can be conveniently rolled, has not half the bearing surface of a chair on the sleeper. With comparatively light traffic the steel rail will last a long time, say thirty years; and in such cases it may fairly be asked why it should be made heavier so as to last fifty years. But the fir sleeper does not last more than seven years, and what is worse it is attended with great trouble in maintaining the gauge. Here therefore the base-plate will be beneficial, only it must be large enough to give nearly as much bearing surface as the chair, and thick enough not to bend, and must be fixed to the sleepers beforehand, like the chair, as shown in Figs. 1 and 2, Plate 118; and the rails must be fixed to the base-plates by steel keys, as on metal sleepers, so as to obviate the necessity for extreme accuracy in the position of the holes in the base-plate for the spikes and for the width of the rail base. Several railways are progressing in this direction with advantage; and in view of the trials now being made on the Furness and other railways it may be hoped that, even with the flange rails and steel base-plates, if something like the same cost be spent upon this plan, an approach will soon be made to the good English roads.

Influence of Speed on safety and economy.—As to speed, the author found by calculations made twenty years ago that the cost of construction of the different Swedish railways was very nearly in proportion to the speed actually run on them; and in Table 3 is shown the widely differing proportion between weight of engines and weight of rails on the Continent and in England. In America this difference is still wider; engines of 60 to 70 tons and trains of 2,000 to 3,000 tons are carried upon a comparatively light road; there however the

rolling stock is all on bogies, and also the weight is distributed on many more axles than in Europe, and the speed is lower. Thus the speed seems to be all important in regard both to safety and to economy, the American freight tariff, as already stated, being only half as high as the English. The distribution of the weight upon a greater number of axles, so as not to exceed a certain load upon each, seems to the author to be a true principle, only so long as the speed is slow. With high speed, say 60 miles an hour, he is of opinion that the rail between the supports of the sleepers has no time to regain its original position between the passage of each wheel and hardly between that of each carriage; so that the weight of the whole train, or at least of the whole engine, acts like one single blow upon the rail from one rolling ball; and therefore it is the total weight of the engine that should properly be taken into account when running at high speed, and not the weight per wheel or per axle. With slow speed it is quite different; and when serving his time with our President at Cardiff the author remembers learning from him that the reason why he could take such heavy coal trains on the Taff Vale Railway without breaking the rails was that the average speed was not more than 12 miles an hour. The extended experience of the President since that date enhances the value of his views on the effect of the rolling stock upon the rail, both as to safety and as to economy; and in following the lines of his recent admirable presidential address on the locomotive engine from almost its infancy, the author has much pleasure in giving his own experience on the rail question, after inspection of very large quantities. The present paper he hopes may be regarded as an expression of gratitude to the President for his unvarying kindness during a friendship of thirty years; and of the wish that the engineers of the two different departments, the rolling stock and the permanent way, may persevere in working together for the common good.

TABLES 1 to 3.

TABLE 1 (*continued on opposite page*).

Bessemer Steel Rails containing high percentage of Silicon.

First series of Tests.

Chemical Test of Elements.

No. of Test.	Carbon.	Silicon.	Phosphorus.	Manganese.	Sulphur.
No.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	0·22	0·38	0·052	0·504	0·064
2	0·47	0·15	0·052	0·828	0·032
3	0·23	0·38	0·010	0·792	0·055
4	0·52	0·18	0·033	0·510	0·059
5	0·31	0·28	0·040	0·936	0·064
6	0·49	0·16	0·040	0·720	0·053
7	0·32	0·18	0·032	0·792	0·068
8	0·36	0·15	Ordinary heats, tested for Carbon and Silicon only.		
9	0·34	0·09			
10	0·32	0·12			
11	0·33	0·13			

(*concluded from opposite page*) TABLE 1.

Bessemer Steel Rails containing high percentage of Silicon.

First series of Tests.

Mechanical Tests of Strength and Hardness.

TRANSVERSE IMPACT TEST.			HARDNESS TESTS.		TENSILE TEST.		
Falling Weight of 1-ton ball. Rail 75 lbs. per yard. Bearings 3 feet apart.			Depth of Indent.				
Height of Fall.	Number of Blows.	Deflection in centre.	Impact of 1-ton ball falling 4 ft. on blunt cone with small end 1 inch diam. placed on rail head.	Pressure of 50 tons on sharp-pointed cone placed on rail head.	Breaking Strain, tons per square inch. Test piece 1 inch diam.	Percentage of Elongation in length of 4 inches.	No. of Test.
Feet.	No.	Inches.	Inch.	Inch.	Tons.	Per cent.	No.
18	1	4·41	0·20	0·39	38·99	22	1
5	3	1·38	0·12	0·28	48·32	6	2
18	1	3·74	0·18	0·39	44·76	21	3
5	3	1·38	0·12	0·28	48·38	3	4
18	1	3·43	0·18	0·35	43·94	18	5
10	3	3·54	0·12	0·28	48·64	5	6
18	1	3·31	0·16	0·35	46·10	15	7
18	1	2·99	0·16	0·35	No tensile tests made from these four casts.		8
18	1	2·99	0·16	0·35			9
18	1	3·43	0·12	0·35			10
18	1	3·35	0·12	0·35			11

TABLE 2 (*continued to page* 326).

Bessemer Steel Rails containing high percentage of Silicon.

Second series of Tests.

Chemical Test of Elements.

Description of Steel.	No. of Test.	Carbon.	Silicon.	Phosphorus.	Manganese.	Sulphur.
Bessemer High Silicon Steel.	No.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
	1	0·36	0·13	0·06	1·00	0·05
	2	0·36	0·15	0·07	0·97	0·06
	3	0·35	0·26	0·07	1·02	0·06
	4	0·36	0·27	0·06	0·96	0·06
	5	0·36	0·27	0·065	1·19	0·05
	6	0·31	0·26	0·055	1·06	0·06
	7	0·41	0·28	0·06	1·00	0·07
	8	0·37	0·08	0·06	0·88	0·06
	9	0·26	0·23	0·07	0·92	0·05
	10	0·28	0·28	0·05	0·90	0·08
	11	0·32	0·25	0·06	1·12	0·06
	12	0·29	0·26	0·07	1·07	0·05
	13	0·32	0·22	0·07	0·92	0·05
	14	0·31	0·27	0·06	0·96	0·05
	15	0·38	0·12	0·07	0·94	0·06
Bessemer Ordinary.	16	0·35	0·06	0·06	0·80	0·07
	17	0·42	0·05	0·06	1·00	0·07
	18	0·40	0·07	0·05	0·92	0·07

(*continued from preceding page*) TABLE 2.

Bessemer Steel Rails containing high percentage of Silicon.

Second series of Tests.

Mechanical Tests of Strength and Hardness.

TRANSVERSE IMPACT.	HARDNESS TESTS.			TENSILE TEST.			
Impact of 1-ton ball falling 15 feet on rail 80 lbs. per yard. Bearings 3 feet apart.	Impact of 1-ton ball falling 5 feet on blunt cone with small end 1 inch diam. placed on rail head.	Impact of 1-ton ball falling 10 feet on sharp-pointed cone placed on rail head.	Pressure of 50 tons on sharp-pointed cone placed on rail head.	Breaking Strain, tons per square inch.	Percentage of Elongation in length of 4 inches.	Percentage of Contraction of original section.	No. of Test.
Deflection in centre.	Depth of Indent.	Depth of Indent.	Depth of Indent.				
Inches.	Inch.	Inch.	Inch.	Tons.	Per cent.	Per cent.	No.
1·89	0·24	0·87	0·24	38·86	23	43	1
2·05	0·24	0·79	0·24	39·68	20	38	2
2·20	0·20	0·71	0·24	47·50	17	34	3
2·05	0·20	0·67	0·24	49·84	14	30	4
2·28	0·16	Broke.	0·24	41·15	18	35	5
2·20	0·16	0·67	0·24	40·64	19	37	6
1·93	0·16	0·63	0·20	54·86	8	8	7
2·56	0·20	0·71	0·24	41·46	18	47	8
2·95	0·24	0·79	0·28	35·11	23	33	9
2·60	0·24	0·75	0·28	39·43	14	31	10
2·36	0·20	0·71	0·24	45·40	18	32	11
2·68	0·24	0·71	0·28	40·64	21	36	12
2·60	0·24	0·75	0·24	40·45	22	31	13
2·48	0·24	0·79	0·24	40·06	23	34	14
2·36	0·24	0·79	0·24	43·50	16	26·5	15
2·09	0·22	0·79	0·26	37·34	22	34	16
1·89	0·20	0·71	0·24	46·61	18	33·5	17
1·93	0·20	0·79	0·24	44·32	17	22·4	18

TABLE 2 (*concluded from page* 324).

Bessemer Steel Rails containing high percentage of Silicon.

Second series of Tests.

Mechanical Tests, Appearance of Fracture.

Appearance of Fracture of broken Ingot.	Appearance of Fracture of broken Rail.	No. of Test.	Description of Steel.
		No.	Bessemer High Silicon Steel.
Solid.	Solid.	1	
Solid.	Solid.	2	
Honey-combed round outside.	Solid.	3	
Solid.	Solid.	4	
Solid.	Solid.	5	
Solid.	Small seam in web.	6	
Solid.	Solid.	7	
Solid.	Solid.	8	
Solid.	Solid.	9	
Hole in centre.	Bad seam in web.	10	
Big hole in centre, 4 ins. × 2 ins.	Bad seam in web.	11	
Solid.	Solid.	12	
Solid.	Solid.	13	
Solid.	Solid.	14	
Solid.	Solid.	15	
No Ingot broken.	Solid.	16	Bessemer Ordinary.
No Ingot broken.	Solid.	17	
No Ingot broken.	Solid.	18	

TABLE 3.

Comparison between Weight of Rails and of Engines.

F = Flange Rail. G = Goliath Rail.
D = Double-headed Rail. B = Bull-head Rail.

Railways.	RAILS. Description, and Weight in lbs. per yard.	ENGINES. Weight in tons, and Number of Wheels.
FRANCE.	Centres of sleepers 3 feet.	
Nord	F 60 without base-plate; F 86½ in 1887.	39, 43¼, 47½, 51¾, on 8 wheels.
Est	F 60 without base-plate; F 88½ in 1887.	42 on 6 wheels; 49 on 8 wheels.
Ouest	D 60 with chairs. D 88 in 1889.	38¾, 41½, 48, on 4 wheels and bogie.
Orléans	D 76 with chairs. D 84 in 1889.	51, 55, on 8 wheels.
État et Midi	D 76 with chairs.	54 on 8 wheels.
Paris Lyon Méditerranée	F 68; F 78 in 1888; F 94 in 1889 with base-plate.	53, 57, on 8 wheels.
BELGIUM.		
État	F 68 without base-plate; G 105 in 1886 with base-plate.	49, 52, on 8 wheels.
Grand Central	F 68 without base-plate.	52 on 8 wheels.
ITALY.	F 72 without base-plate; F 84 in 1889.	47.
ENGLAND.	Centres of sleepers 2 ft. 6 ins.	
London and North Western	B 90 and B 82; with chairs 40 to 50 lbs. each.	42 on 6 wheels.
Great Northern	B 85; with chairs 40 to 50 lbs.	42 do.
Midland	B 85; do. do.	43 do.
Great Western	B 86; do. do.	42 do.
Great Eastern	B 86; do. do.	42 do.
North Eastern	B 90; do. do.	43 do.
South Eastern	B 84; do. do.	42 do.
London Chatham and Dover	B 84; do. do.	42 do.
AMERICA.	Centres of sleepers 2 feet.	
Pennsylvania	F 60 to 80 without base-plate.	60 on 8 wheels with bogie.

Discussion.

The PRESIDENT announced that Mr. Sandberg had presented to the Institution a framed portrait of the late Dr. Percy, who had perhaps done as much for the iron and steel trades of this country as any other man; and the welcome likeness now received would help to perpetuate their remembrance of the important work he had accomplished.

The paper just read had been placed first on the list for the present meeting, because, although the author was not a Sheffield man, the first steel rails successfully produced by the Bessemer process had been made in Sheffield, and the manufacture of steel rails had formerly held an important place among Sheffield industries. There were some samples of rail sections exhibited by the author, which showed the effect of the web of the rail not being perfectly solid, from the causes mentioned in the paper.

Mr. SANDBERG considered himself particularly indebted to Sheffield, because it was here that in 1862 he saw the first steel rails made at Messrs. John Brown and Co.'s Works; and as to the quality of those rails he thought it might safely be said they had not been surpassed. He was very glad to know that Sweden had acknowledged their quality, by giving to the managing director of the works, Mr. John D. Ellis, the highest decoration bestowed for industrial achievements, namely Chevalier of the order of the Wasa, in recognition not only of the good rails but also of the good armour-plates produced at these works.

He had recently received four letters from engineers to whom he had sent copies of the paper just read. One was from Mr. Werchovsky, engineer-in-chief of the Russian State Railways, who referred to the question raised at last year's congress in Paris as to the influence of silicon in steel rails; he was very grateful for the experience gained by the experiments that had lately been made, and he also expressed a hope that the next congress at St. Petersburg in 1892 would thoroughly clear this matter up. Another letter was from Professor

Tunner, of Leoben, Austria, who was now eighty-three years of age, and who hoped that the introduction of the Goliath rail would go on a little faster, as a true and practical help both for the railways and for the steel trade and for the workmen employed therein. Another was from Dr. Wedding of Berlin, who was at the German School of Mines and the Railway Department, and who was about to institute a commission upon the improvement of the permanent way, for deciding on the best form of rail and of the permanent way generally. Dr. Wedding trusted that Germany would be at the head of the railway world in having the best road. Germany was certainly very far from such a position at present, but he hoped it would progress a little more actively in that direction. Dr. Wedding had also sent some microscopic observations upon the steel used in the Goliath rails and in others. The results were the same as those previously ascertained, namely that, the thicker the head, the less solid was the steel inside it. The fourth letter he had received was from Mr. Meyer, engineer of the Simplon Railway, Switzerland, who was thinking of adopting the Goliath rail. With regard to the influence of silicon in making the steel quiet in casting, Mr. Meyer pointed out that the same object could be attained by the use of aluminium; and he stated that works had been started at Schaffhausen for the production of aluminium, which sold at about eight shillings a pound, and that 0·1 per cent. would be sufficient to make the steel solid. Mr. Sandberg knew this before; but what would be the cost? Increasing the cost of steel rails by about eighteen shillings per ton through the use of aluminium he thought was out of the question: apart from the difficulty of getting 0·1 per cent. properly mixed in such large quantities of steel. Either aluminium would have to come down in price, or its use would be limited to some finer purpose than rails.

He had also received a letter from Sir James Ramsden, who regretted his inability to attend the present meeting, and wrote in reference to the Goliath rail "You may make use of any reasonable language in favour of it in my name." Sir James Ramsden had been the first in this country to try the Goliath rail with base-plates on the Furness Railways, and he had thus done a great deal to promote its use.

(Mr. Sandberg.)

He wished to take this opportunity of recording how well he had been supported, first by the English rail-makers, and then by English engineers, who had so kindly assisted him in solving the problem of steel rails, and in clearing the matter up as far as was possible. They were entitled he considered to the largest share of any compliments that had been passed upon himself.

The question for discussion presented itself in two divisions. There was first the influence of silicon upon steel, which was a subject not new to Sheffield. On this matter he was old enough not to be caught at the Paris congress by any new composition, or to be misled into advocating a high percentage of silicon for heavy ingots, which no doubt would have been a failure. The percentage of silicon however, he thought, needed but little discussion; and he hoped that attention would not be bestowed upon this so much as upon the second point, namely the importance of the road, and particularly the problem of bringing the road with flanged rails up to the standard of the best English lines. This was a very important matter, indirectly for England, but directly for all other parts of the world using flanged rails, where the strengthening of the road in proportion to the increased weight of the rolling stock was usually attended with great difficulties. The locomotive engineer had a certain work to do; the traffic was increasing and the speed was increasing, and it was not for his own pleasure that he increased the weight of the engines, but he was compelled to do so. Consequently the permanent-way engineer was often left behind, owing to the difficulties in his way rather than to any economical reasons. To change the section of rail, and to change the crossings and the points in conformity with the rail section, was no doubt a difficult matter; and the existing section was often adhered to, until the disproportion between its strength and the weight of the rolling stock led to accidents. That was particularly the case on the Continent. England he believed could show a good example of the two departments going on well together; while on the Continent the use of the flanged rails for twenty or thirty years without increasing their section had brought them into discredit. The problem therefore was how to adhere to the use of the flanged rails, while

so increasing their strength as to approach the solidity of the English road. With regard to the base-plate, he could not but believe that its adoption must come about, although it would be attended with a great deal of trouble for many reasons.

Mr. E. Windsor Richards, Vice-President, thought the best thanks of the Institution were due to the author for his able paper; he could not help being struck with the sound common sense and moderate views expressed throughout it. All would endorse the wish expressed at the end, that the engineers of the two departments of railway management might persevere in working together for the common good, so as to enable trains to be run at higher speeds and with greater safety. As far as locomotives were concerned, the way in which they were turned out by the leading locomotive superintendents in this country could not fail to command admiration; but as to the permanent way he did not think quite the same could be said. There was no doubt that, although the railways in this country were much in advance of continental and other nations, there was a great deal still to be done in improving the permanent way for high speeds. The brave little kingdom of Belgium was going ahead in laying down the heavy rails described in the paper; and he was delighted to see a move being made in that direction on the continent, for hitherto when travelling abroad he always felt in danger of derailment, after having had one experience of it.

With regard to the length of rails, which was a very important point in a good road, he remembered the time when rails had a normal length of only 18 feet. The author had shown clearly the weakness of the joints; and even with the present improved joint he owned that it was still a weak point. If that were so, why not have fewer of them? The normal length of rails was now 30 feet. It was well known that for many years past the Meridionali Railways in Italy had been using 12-metre rails, say 40 feet. When 30-feet rails were adopted in England, it was said that they could not be handled; but if Italians could handle 40-feet rails, he thought Englishmen could also.

(Mr. E. Windsor Richards.)

With regard to steel rails considered chemically, although the Paris congress had decided that a hard rail was the safest, he did not himself believe that it was so, and would not accept that decision. In page 302 Mr. Werchovsky had given what he called an average chemical composition of Russian steel rails, in which it was alarming to see so much as 0·18 per cent. of phosphorus. If this was the average, what was the highest percentage? It could now almost be understood how it was that the imperial train came to grief (29 Oct. 1888) on one of the Russian lines. The author had wisely abstained from giving any empirical chemical composition for steel rails, although if the paper were followed through it would be found that an analysis could be obtained from it; and this agreed very nearly with what he had himself advocated for a long time past, and had adopted in the manufacture of many thousands of tons of rails. Good steel rails made at the present day he considered should contain from about 0·35 to 0·40 per cent. of carbon. The silicon question had been most ably dealt with by the author, who had devoted a large amount of time and energy to its elucidation, in order to get it settled in England. Some engineers had a wholesome horror of silicon in rails. In Germany a proportion as high as about 0·25 per cent. was believed in; but he considered it should not exceed 0·10 per cent. The favourable effect of silicon had been mentioned in the paper (page 303), and he thought that its favourable effect for rails ceased after reaching 0·10 per cent. The percentage of manganese had not been much dealt with in the paper. Up to 1 per cent. he thought that manganese did not unfavourably affect a rail cold, but it did affect very favourably the making of a good clean rail hot; and he had for many years advocated a proportion of from 0·75 to 1·00 per cent., for the reason that this ensured obtaining a thoroughly good clean rail, free from small surface cracks, which in very soft steel were a source of danger, because they might lead to a fracture at any time. Phosphorus had been a *bête noire* for many years, and he had himself had ample reason for regarding it in that light. The percentage of phosphorus he considered should be as low as possible, and in no instance should it be allowed to exceed 0·10 per cent. It had sometimes been said that phosphorus was not a hardener; but

at any rate it was the worst metalloid that could be put into steel, because it made the steel extremely brittle. Carbon was a hardener, but it also gave toughness. Phosphorus he believed was a hardener too, but it gave brittleness, and was therefore much to be avoided.

As to mechanical testing, he considered that tensile tests for steel rails were more nice than wise. In order really to know what sort of steel the rails were made of, there should be a chemical analysis to begin with, and then the physical test of a falling weight, say two blows from a 1-ton monkey falling 15 feet. This was quite sufficient for testing rails.

Mr. David Evans believed the Barrow Hæmatite Steel Works had been the first in this country to roll the Goliath rail for the Victorian Government; and also for the Grand Trunk Railway of Canada, according to the author's first design of 1886 without base-plates, as shown in Fig. 4, Plate 119. He had also rolled there some for the Furness Railways, and for use on the railways belonging to the works, and had found no difficulty in doing so. He had also manufactured the steel base-plates, as shown in Fig. 2. These rails and base-plates had been laid on the Furness Railways; and during the present year the Whitehaven tunnel, about 1,400 yards long, had been relaid with 90 lbs. flat-bottomed rails, base-plates, and steel keys, thereby enabling something like 3 inches more headway to be gained. From information which he had received from the engineer, Mr. Stileman, it appeared that the road so laid had given great satisfaction. Similar rails and base-plates had been laid also on a portion of the lines in the Barrow works, and thus far he was much pleased with the result.

In regard to the question of chemical analysis, he quite agreed with what Mr. Windsor Richards had said. From his own experience he considered that the carbon in steel rails should not exceed 0·30 or 0·40 per cent. With reference to silicon he also agreed with Mr. Windsor Richards that it should not go beyond 0·10 per cent. He had been informed by Mr. Stileman that about the first steel rails rolled in Barrow were those for the Furness and Midland Railway in 1868 or thereabouts. They were in the road in

(Mr. David Evans.)

Wennington tunnel for twenty-one years, and lost during that time 21 lbs. per yard. The following was an analysis of one of the rails :—

Carbon	0·300 per cent.
Silicon	0·329 „
Phosphorus	0·053 „
Manganese	0·360 „
Sulphur	0·016 „
Iron	98·942 „
	100 000

This carried out Mr. Sandberg's suggestion as to large and small ingots. A section of the rail as rolled and as worn was shown in Fig. 8, Plate 120.

Mr. ROBERT A. HADFIELD, as reference had been made in the paper (page 306) to his experiments, said that, although he had not had a large experience in the question of steel rails, he considered it highly important to come to some definite determination if possible respecting the chemical composition of rails, because he believed there were four million tons per annum made in England and America and on the Continent, and there did not appear to be any very definite agreement on the subject, each maker having his own opinion. The author had expressed his belief (page 301) that the fact of the early Bessemer rails wearing so well was due to the slow-running mills and hammered blooms; but from Dr. Dudley's experiments in America it had been clearly shown that this was rather owing to the higher percentage of carbon in the steel. It was certainly a noteworthy conclusion at which the congress had arrived, as pointed out by the author (page 301), that the hard rail not only wore the best, but was also the safest. Possibly that might be to some extent owing to the fact that the point of permanent set in hard steel was much higher than in soft steel, and consequently deformation did not take place so rapidly. As had been properly pointed out in page 303, the difficulty of getting the most suitable quality of steel for rails was probably owing to the fact that it often happened no distinction was made between the various uses to which

steel was put. It would be much better, he agreed, if the chemical composition of steel were left to the maker; while at the same time it would still be advantageous if some determination could be arrived at as to what was the best composition.

As to the use of silicon, no doubt it might be advantageously employed, owing to the fact that it gave great soundness. The fact that aluminium also gave soundness had been mentioned (page 329); but the 0·1 per cent. named by Mr. Meyer would mean an addition of about eighteen shillings per ton to the cost of the steel. Silicon he thought certainly raised the point of permanent set, and its use might be found of more importance if it could be clearly proved that this was so. The remarkable rail which Mr. Evans had just referred to (page 334), as lasting twenty-one years and containing 0·329 per cent. of silicon, should induce a favourable opinion of the value of silicon. It had also been pointed out in the paper (page 303), and was well known, that the further advantage of using silicon was that it caused the steel to settle or "pipe," absorbing the gases, and thus rendering the metal sound and devoid of cavities. As a steel founder he considered this function was very important, because, if the steel could be got to pipe, it was sure to be sound below the depth to which the piping extended down. In such a rail as was here shown by the author, having an internal crack where a cavity had been closed up in the rolling, the defect was not due to the unsoundness of the steel, that is, speaking of unsoundness in the true sense of the word; but simply to part of the ingot having been rolled in which the piping had occurred. The piped portion he thought could by proper appliances be removed from the ingot, or so arranged that it should be found in the head or waste portion of the ingot, as was done in castings; and he believed that Mr. J. D. Ellis, of the Atlas Works, Sheffield, had made some experiments with the special view of getting rid of piping in the ingots by means of feeding heads of special shape. In steel founding it was necessary to put a certain head or feeder of metal on the top of the mould, in order to get sound material in the casting; and there seemed no reason why the same object could not be accomplished with ingots by the same means. It was not a difficult

(Mr. Robert A. Hadfield.)

matter to put a sand head on the top of the ingot mould, and would mean little extra expense. Having had special experience in making manganese steel, which piped much more than ordinary carbon steel, and even more than silicon steel, he had to a great extent done away with unsoundness in the ingot by such means. That silicon was of use in increasing the durability of rails was clearly proved by the rail of which Mr. Evans had spoken, and was confirmed so clearly by Mr. Sandberg's tests. It might be well however for this point to be studied a little more. He thought also that the exact hardness of the samples experimented upon by Mr. Sandberg would have been better determined by means of a hardness-testing machine, such as Professor Turner had devised at Mason Science College, Birmingham. Though such a suggestion might perhaps be regarded as going somewhat in advance of the times, yet if in the future a locomotive should be designed to run at seventy to ninety miles an hour, it would no doubt be necessary to take much more care as to what kind of rail was used. In that event, possibly manganese steel, of which he had recently given some particulars,* might come in advantageously, having a tensile strength of from 50 to 60 tons per square inch with an elongation of 30 to 40 per cent., while its hardness he believed would certainly be far in excess of that of ordinary carbon steel. Recent tests of this steel for dredger pins, in the dredging department connected with the new Preston Canal, had given highly satisfactory results: an ordinary steel pin, made of hard steel with 0·4 per cent. of carbon, wore out in about three months; whereas a pin of manganese steel had lasted for nine months, and was hardly worn at all. Having been in correspondence with Mr. Sandberg for some time on the subject of rail steel, he certainly thought the present paper had given some valuable information, for which engineers and rail makers must alike feel greatly indebted to the author.

Professor J. O. Arnold considered the general basis upon which the paper was written was good; but, while agreeing with some of

* Proceedings Institution of Civil Engineers, 1888, vol. xciii, pages 1 and 61.

the conclusions to which the author had come, he took exception to others. The first page of the paper he regarded as important in recognizing an intermediate class of hardness. The ordinary hardness of steel was produced by plunging heated steel into cold water; but there was no doubt an important intermediate state existing, in which various degrees of hardness could take place, as the author had pointed out, from prolonged rolling when the steel was getting cooled, and from hammering. That statement he regarded as a valuable addition to the paper.

In page 303 the author dealt with chemical action in the Bessemer converter; and with his views on this subject he could not agree at all. The benefit conferred by silicon was considered by the author to arise "from its affinity for oxygen, whereby it has the effect of reducing the oxide of iron floating on the liquid steel after the sudden blowing in the converter." Now as a matter of fact there was no oxide of iron floating on the liquid steel after blowing. When a blow started, the iron contained an average of perhaps $2\frac{1}{4}$ per cent. of silicon; as the blast passed through the liquid steel, the carbon and the silicon were oxidized almost equally, the carbon passing off in a gaseous form, while the silicon floated as an acid silicate of iron and manganese on the top of the bath. The author said that the silicon "first forms silica, which then takes up more oxide of iron and forms silicate of iron or slag, which floats on the top of the metal in casting, and absorbs all the carbonic oxide gas as it rises, thus making the metal very quiet in the mould." There was no slag floating on the liquid steel ingot; and any one who had carefully watched the teeming of Bessemer steel in the mould would know that a great evolution of gas took place from the bottom of the ingot. The author further said that the silicon consequently rendered steel castings solid, as was well known in steel foundries, where 0·25 per cent. of silicon was the usual proportion for obtaining a solid casting. There were many steel manufacturers in Sheffield who he thought would be greatly delighted if they could get solid steel castings with 0·25 of silicon. As a matter of fact he believed that the proportion of silicon used in Sheffield approximated more nearly to 0·50 per cent. in steel castings; and even with this

(Professor J. O. Arnold.)

percentage unsound castings he thought had been known to be produced in Sheffield. Practically he was himself inclined to regard the action of silicon on steel not as a chemical but as a physical action. With 0·50 per cent. of silicon he believed a perceptible lowering took place in the fusion point of steel, in consequence of which it became more fluid, and the carbonic oxide with which the liquid metal was thoroughly saturated had time to get off before the metal set; it rose from the bulk of the ingot, and accumulated in the centre, forming what was known as the pipe. In page 305 it was stated that "silicon up to 0·20 or 0·30 per cent. certainly makes the steel quiet in casting, and free from small honeycombs or blisters; but in cooling from a fluid to a solid state it draws or shrinks much more than rail-steel containing only 0·10 per cent. of silicon, or less." That was because the bubbles of occluded carbonic oxide gas and hydrogen had time to get away from the liquid metal of the ingot. Instead of having bubbles scattered throughout the ingot, the metal was able to set solid, and there was consequently a shrinking. It was also stated in page 304 that "silicon up to 0·30 per cent. makes no visible difference in the hardness, so far as is shown by deflection under the falling weight or by impact or by tensile tests: the different results obtained being altogether dependent upon the proportion of carbon." In page 307 this statement was further emphasized by the remark that, "as regards the hardness of steel rails, it would appear from these experiments that silicon is of no consequence, everything depending upon the percentage of carbon and phosphorus." From his own experience he could bring numerous results to prove that this view was altogether erroneous. But there was no necessity to go further than the paper itself, in which the author had produced some excellent results entirely disproving the above statement. Thus in Table 2, page 324, it would be found that test No. 1 and test No. 4 represented two steels practically identical in composition, except with regard to the percentage of silicon, No. 1 containing 0·13 per cent. and No. 4 containing 0·27; the percentages of carbon, phosphorus, manganese, and sulphur were practically the same. Whether the increase of silicon from 0·13 to 0·27 per cent.

hardened the steel could readily be judged by the mechanical tests, page 325; and it would be seen that in test No. 4 the steel containing 0·27 per cent. of silicon was hardened to such an extent that the elongation in the length of 4 inches had fallen from 23 to 14 per cent. Still better examples were also given. Comparing test No. 7 of Bessemer high silicon steel with test No. 17 of Bessemer ordinary steel, it would be seen that the analysis was identical, with the exception that in No. 7 the steel contained 0·28 per cent. of silicon as against 0·05 per cent. in No. 17. With 0·28 per cent. of silicon the steel was so hard that the elongation in 4 inches length fell to 8 per cent.; whereas in the steel containing only 0·05 per cent. of silicon the elongation was 18 per cent. No more conclusive proof he thought could be given of the hardening effect of silicon than was furnished by these results. In page 305 it was stated that "silicon at 0·20 per cent. and upwards gives a sound ingot with a clean solid top, which rolls out into a rail with fewer defects than steel that contains only 0·06 per cent. of silicon, other ingredients being the same." Yet in Table 2, page 326, it would be found that in test No. 6, containing 0·26 per cent. of silicon, the fracture of the rail showed a "small seam in web"; and in test No. 10, with 0·28 per cent. of silicon, there was a "bad seam in web"; again in test No. 11, with 0·25 per cent. of silicon, there was also a "bad seam in web"; whereas in the three tests of ordinary Bessemer steel the fracture was in each instance solid, the several percentages of the silicon being 0·05 and 0·06 and 0·07. It was true that in page 305 the recommendation was given that "more than 0·10 to 0·15 per cent. of silicon should not be aimed at"; but he thought it would be admitted that the general tendency of the author's results in Table 2 was to give the impression that even 0·30 per cent. of silicon in a rail was not injurious. From this impression he entirely differed; and he fully endorsed the author's sentiment expressed in page 308, "Why then overdo the hardness and thereby risk the safety?" and he shared his determination that he would "not let himself be led astray by any wonderful chemical composition of steel rails." He therefore hoped that no engineer would be carried away with the idea that 0·30 per cent. of silicon in steel rails could be used with

(Professor J. O. Arnold.)

impunity: or the services of the chemist and druggist would be of no avail whatever, and those of the undertaker would be required.

Mr. JEREMIAH HEAD, Past-President, desired to speak not from the point of view of the rail-maker or chemist, but from that of the mechanical engineer. In page 311 he noticed that in the opinion of the Paris congress "even the double-headed rails and chairs laid on half the railways in France, although the rails are somewhat old-fashioned, were considered superior to the flange rail." In page 314 the author seemed to assume an attitude of apology for the flange rail, saying that he had no idea of introducing it on English lines. From the mechanical engineer's point of view it certainly seemed to him that the flange rail was altogether superior in form to the double-headed or bull-headed rail. Regarded as a girder, the bulk of the material in the flange rail was placed at the top and the bottom, exactly where it was wanted. As giving a means of securing it rigidly to the sleeper, what could be more advantageous than that broad flange at the bottom, which also assured lateral rigidity? Again in providing ample bearing surface on the sleeper it was evident that the flange rail was vastly superior to the double-headed or bull-headed rail. With the present experience of railways and railway working it appeared to him that no one would now ever dream of inventing such a form as that of the double-headed rail. When it was first devised, it was with the idea already alluded to in page 314, that when the top was worn out the rail should be turned over so as to use the bottom. The form was so bad for holding it steady against side thrust, that it was indispensable to have chairs, in order to give it an artificial width of base which it did not itself possess. Where it rested on the chairs it became indented; and every one who had examined double-headed rails when taken up after some length of use would have seen that the indentations were very marked. Consequently it appeared to him that from every point of view the flange rail was the right form, and needed no apology whatever. The paper had implied that there was no great extent of permanent way laid in this country with flange rails. This he believed was quite true. On the North Eastern Railway

however there were at the present time sections laid with 90 lbs. flange rails and steel sleepers. One of these sections he had often watched, to see how it behaved under the stress of a very heavy traffic; and he had travelled over it a great number of times. As far as he could observe, it was still perfect, although it had been laid down two or three years at least. It seemed quite successful in regard to the rails being held securely in their fastenings, and also in every other respect; and the running was beautifully smooth over it.

As to the proper chemical composition for steel rails, a considerable difference of opinion had been expressed. The author advocated that the amount of silicon should be left to the maker of the rail; and it would be seen from the remarks of the previous speakers that each of them had his own idea as to the proper composition for rail steel. It had been stated by the author that a great deal of his knowledge had been gleaned from the manufacturers of rails. He would therefore suggest whether as a matter of principle it would not be better to leave the composition of the rails entirely to those who had necessarily so much experience in the matter, and who were continually analysing the rails. It appeared to him that the specified tests might very properly be all physical tests: exclusive however of tensile tests, which in the case of rails were obviously superfluous. A rail of 80 lbs. section would require a stress of about 320 tons to pull it apart, and before that could be accomplished it would contract something like 30 or 40 per cent. Tensile tests were quite unsuitable for steel rails and tires, which were subject to conditions that did not pertain to any other applications of steel. What was wanted in rails was first of all safety, that is, freedom from brittleness; and secondly power of resisting abrasion. The drop test was perhaps the best that could be devised for detecting brittleness; but, as far as he knew, there was at present no means whatever of testing power of resisting abrasion, unless Mr. Turner's machine for testing hardness, which had been alluded to by Mr. Hadfield (page 336), could be so considered. A machine was wanted, he thought, which would test the power of resistance to abrasion in the way in which a rail was really subjected to it in actual practice; and he did not see any difficulty in scheming such a machine, if

(Mr. Jeremiah Head.)

proper consideration were given to the subject. As a matter of principle therefore he recommended that railway engineers should leave the composition of the steel to the makers, and should simply take care that the rails were tested with proper machinery in such a way as would really prove that they would do what was wanted of them, whatever their composition might be. It was quite conceivable that three or four different analyses might produce equally good results in regard to safety and durability. By specifying an analysis as well as physical tests, engineers appeared to him to be taking the responsibility off the makers on to themselves; and if the rails failed, the former might properly claim to be released from responsibility, if the analysis was within the specified limits.

Mr. EMERSON BAINBRIDGE said that, Mr. Head having spoken as a mechanical engineer, he should himself like to speak as a manufacturer and as a freighter of some thousands of tons per day on some of the railways in the Midland district. In pages 319–320 of the paper there occurred a sentence which was pregnant with interest, not only to engineers, but especially to the manufacturers of Sheffield. Referring to the character of the railway traffic in America, with engines of 60 to 70 tons taking trains of 2,000 to 3,000 tons over a comparatively light road, the author then added "Thus the speed seems to be all important in regard both to safety and to economy, the American freight tariff, as already stated, being only half as high as the English." At the present time, when the question of railway rates was undergoing so much careful consideration by the traders of this country, and was now being investigated by a parliamentary committee, the various means of diminishing the rates upon heavy goods formed a subject of surpassing interest, especially to the towns in the Midland counties; and if the secret of the means of doing so could be found in the American system, it might be well worth while for railway engineers to turn their attention in that direction more than they had previously done. The only variation from the ordinary mode of carrying traffic in this country appeared to him to be that in America there were engines of larger size than in England, and on comparatively light roads.

Mr. W. FORD SMITH, referring to the question whether steel was stronger or weaker in its hard and brittle state, mentioned that, if a piece of tool steel were hardened in one portion while the rest remained soft, the hardened portion would not give way, but the soft portion would. In testing drills especially, he had repeatedly seen that the soft portion twisted, while the hardened portion retained its shape and did not give way at all. He should be glad if some engineers of experience would explain why that was so. It appeared to himself to support the view entertained at the Paris congress, that hardness was an element of strength and safety in rails. Engineers seemed to be now rather drifting into the conclusion that hardness was not an element of safety, but of weakness.

Mr. BERNARD DAWSON asked if the author could give any idea as to how many miles of railway in this country were laid with flat-bottomed rails. He believed that the whole of the Eastern and Midlands, and a good deal of the Bristol and Exeter and the South Devon and Cornwall lines were laid with flat-bottomed rails, those on the Eastern and Midlands line being laid on transverse sleepers.

The PRESIDENT said it was true that they were flat-bottomed rails on those lines, but on the Bristol and Exeter, the South Devon, and the Cornwall Railways they were bridge rails laid on longitudinal sleepers, and were not flat-footed rails in the sense of the flange rails described in the paper, which were laid on transverse sleepers.

Mr. EDWARD P. MARTIN, Member of Council, could not allow the paper to pass without adding his testimony to the continuous efforts made by the author to bring the views of engineers and manufacturers together on rail making. He knew no one who had done so much in that direction as Mr. Sandberg. There was one point in the paper from which he rather differed, namely as to the effect of phosphorus as a hardener; he thought that it was not a hardener in the proper sense of the term. By adding even so large a quantity as 0·50 per cent. of phosphorus to steel, it was rendered weak and brittle, but not hard. It did not give what he might call "body" to the metal, in

(Mr. Edward P. Martin.)

the same way that carbon did. Chemical analysis he thought was very much in the same category as figures, which could be made to prove almost anything. It was unfair to take a few isolated tests, and argue from them what the results would be. With regard to silicon for instance, he had made some experiments many years ago as to its effect on rails; and by bringing down the carbon to a very low point he had been able to use as much as nearly 1 per cent. of silicon in a rail, which rolled well and stood a heavy falling blow. A very small amount of difference in certain ingredients varied the tests to an enormous degree; and perhaps still more depended upon the way in which the metal was treated, namely whether it was cast or rolled at a high or low temperature. He was beginning to think that some of the puzzling questions in connection with steel depended very much upon the temperature at which the steel had been made, as well as upon its constituent elements. One of the reasons why the flange rail had been laid on the North Eastern Railway was the difficulty of making steel sleepers of such a form that a bull-headed or double-headed rail could be as easily fastened to them as a flange rail.

Mr. ARTHUR PAGET, Vice-President, thought the drift of some of the remarks which had been made seemed to be to depreciate chemical analysis; but if such analyses were carefully made, and if too large and too positive deductions were not drawn from an insufficient number of analyses, they could not fail to be of value. In this connection he might call attention to the fact that the Institution had recently appointed a committee to investigate the very subject now under consideration, namely the wonderful effect produced in some metals by a very small percentage of alloy. As the result of this investigation he had little doubt that the value of chemical analysis would be more than ever confirmed, and it would be found that a great deal of good would result to engineers and others by carefully watching the effects of a very small percentage of different alloys.

Mr. J. HARTLEY WICKSTEED, Member of Council, thought a simple explanation might be given of the drill tests referred to by Mr. Ford

Smith (page 343), where a drill was hardened through half its length and kept soft in the other half. The hardened portion of the drill was stronger under a statical load, but it was not stronger for work put upon it by impact. If the drill was tested under a statical load, it would be found that the harder portion would stand the greater load; but in testing by hammering it would be found that the softer portion would stand a great many more blows than the harder. A rail had to stand something in the nature of impact: the rolling load came so suddenly upon it that the strain was of the character of impact; and therefore the true way to ascertain the strength of a rail or anything else to withstand impact was to see how much mechanical work it would absorb before it broke. For testing a very hard rail by direct tension, Mr. Head had mentioned (page 341) that a section weighing 80 lbs. per yard would require about 320 tons to pull it apart. Such a pull, however superfluous might be the tensile test for rails, would not be in the slightest degree impracticable. Cables of 80 feet length, or double the ordinary length of railway rails, were put into a machine and tested with a load of occasionally 240 tons, in order to reach their actual breaking load. A rail 30 or 40 feet long could just as easily be put into the testing machine; and if it were a hard rail it might be found to take over 300 tons to pull it asunder, but it would only stretch about 6 inches. The mechanical work absorbed by such a rail would therefore be 300 tons lifted 6 inches. But a softer rail might yield at 200 tons, and might stretch 6 feet, and the mechanical work so absorbed would be eight times as much as by the harder rail; therefore the softer rail would be capable of withstanding so many more blows tending to deflect it. Hence by watching the property of hardness combined with the power of elongation, he thought that everything would be ascertained which could be known physically about a rail. If a first-rate rail, such as that mentioned by Mr. Evans (page 334), which had been twenty-one years on a road where there was plenty of hard traffic, were put into a testing machine and made to record its own story autographically, and show exactly at what strength its first set took place, what was its ultimate strength, and what its total

(Mr. J. Hartley Wicksteed.)

extension, it would then be known what physical properties ought to be looked for in a rail that should stand good service; and it could be verified exactly in regard to any future rails whether they were of the same quality.

Here in Sheffield it was of course natural enough that much attention should be paid to the metallurgical aspect of a paper like the present; but the author had expressed a hope that the discussion would be directed to some extent to the mechanical aspects of the subject; and from a mechanical point of view he certainly thought the suspended fish-joint was one of the most interesting features of the paper. The explanation given by the author of the reasons why the suspended fish-joint was a better form of joint than the joint made in the chair or on the sole-plate was new to himself, but it commended itself at once as soon as it was stated, namely that the chair acted as an anvil upon which the end of the rail got beaten down. He thought indeed that the merits of the suspended fish-joint might with advantage be gone into a little further, by looking at it in the following way. When a rail rested upon two chairs, and the load came on it between them, the deflection of the rail between the two points of support caused an elevation of the portion beyond the fulcrum. If a rail end was resting half way into a joint chair, it would be raised with an enormous leverage by the load between the chairs, the fulcrum being so very close to the rail end; and it would be impossible to keep the rail end from working up and down in the chair. But if, instead of making the rail joint in the chair, the rail end were taken half way across the interval towards the next chair, it would then have the same leverage over the fulcrum as the deflected portion, and the load would have no mechanical advantage of leverage over the rail end which required to be held firm. In that way the suspended fish-joint midway between the chairs had an advantage in holding the rail end, on account of having more leverage to hold it down; while at the same time, when the blow of the rolling load came upon the rail end itself and beat it down, there was no anvil underneath to uphold it as a chair did, and cause it to be destroyed.

Mr. Jeremiah Head, Past-President, pointed out that he had not apprehended any difficulty in testing rails up to a total tension of 320 tons. What he had argued was that a rail weighing 80 lbs. per yard would require at 40 tons per square inch about 320 tons to pull it apart; and he apprehended that no strain to which it could ever be subjected in work would be anything like that; and not only so, but before it gave way it would have to stretch 12 per cent. at least of its length, and contract something like 30 per cent. These were conditions which manifestly did not pertain to rails in actual practice.

The President said that, having himself been for a considerable portion of his life working on railways, he considered the flange rail was about the worst form of rail for keeping the road in order. The whole length of the Metropolitan Railway, when he joined it eighteen years ago, was laid with a rail of that section; but the difficulty was in maintenance, not in the rail itself. To make good points and crossings with a flange rail having a broad flange at the bottom involved a great deal of trouble, and a great disadvantage in cutting away one side of the rail, leaving the other side then very weak. Whenever a rail had to be changed, the trains had to be stopped for about an hour in order to get it out and put another in; whereas with the bull-head form at present in use a rail could be taken out and another put in in six minutes. Considering the rail as a girder, he could not see that it made any difference whether the metal at bottom was spread out in a flange or collected in a bulb; so long as the weight of metal was the same, the rail would be equally strong as a girder.

Allusion was made in page 301 to the former use of hammered blooms for the manufacture of steel rails; and although the steel-rail trade had practically deserted Sheffield, or Sheffield had given it up for something better, he believed all rail makers would admit that the hammered steel rails made in Sheffield twenty-five or twenty-six years ago were better than any that had ever been rolled since. The first steel rails laid on the Taff Vale Railway were put down more than thirty years ago, weighing only 75 lbs. to the yard; and

(The President.)

they had carried the entire traffic, which on that railway was not light, for more than twenty years. It was true the speed was slow, not exceeding twelve miles an hour; but the rails were still good after twenty years' work, which was a long life-time, and he was sure that rails manufactured at the present day would not last so long.

As to the question of high silicon steel, he had had one experience of an extraordinary mixture of rail steel. The rails were supposed to contain about 0·40 per cent. of carbon, and they actually contained 0·584 per cent. as an average of three samples. The amount of silicon in the same three samples averaged 0·191 per cent., but one sample contained 0·309 per cent. The phosphorus amounted to an average of 0·085 per cent. The manganese was also exceptionally high, averaging 1·234 per cent. In the falling test the height of fall was reduced from 20 feet to 10 feet; the rails tested with this reduced fall were broken. As the quantity was not large, he had them sent to London, and they were put down on the Metropolitan Railway in 1874; and six trains an hour, of 125 tons exclusive of passengers, had been running over them for eighteen hours a day ever since, and not a single rail had yet been taken up. Four years ago the rolling marks were not out of them. There was therefore something to be said even for what would be considered chemically bad rails. In that sense they were undoubtedly the worst rails he had ever put down: he had been almost afraid to put them down in a curve or in a tunnel, but had chosen a straight piece of road; and the rails had been in use from that time till the present.

Mr. SANDBERG, in reply, thanked Mr. Evans for the assistance afforded by his remarks (page 333), and also for having been the pioneer in making the Goliath rail in England and in using it as well. To Mr. Hadfield he was much indebted, because when preparing the paper he had had the benefit of two or three visits from him, and he entirely agreed with him on the question of silicon. He only differed from Mr. Hadfield in regard to his recommendation for curing the piping by putting a head on the ingots. That would materially increase the cost; and anything that would increase the

cost would be out of the question. The fact was that the shrinkage was not only on the top, but also in the middle of the ingot. Therefore there was a natural danger of unsound rails as soon as large ingots were employed. In keeping to small ingots there was safety and even advantage.

There was no doubt a benefit from the use of silicon. Professor Arnold had uttered a warning against the use of as much as 0·30 per cent. of silicon in the rail (page 339); but independent facts had been mentioned by Mr. Evans and other speakers, which showed that such a percentage gave very good results. There was nothing more dangerous than considering single tests and drawing conclusions from them. He happened to know of 8 000 tons of rails, of which he was confident that every rail contained between 0·20 and 0·30 per cent. of silicon. They had been put down in a country with a very cold climate, and had been in use for six years. During the time of making and inspection not one of them could be broken with the ordinary test of 1 ton falling say 15 feet. He had obtained a statement of broken rails from all the different makers during the last year, and there were only half as many broken as the year before, because the winter had been so mild; but the curious thing was that out of 6,000 or 8,000 tons—four rails to every ton, making therefore 20,000 to 30,000 rails, all of which contained as much as from 0·20 to 0·30 per cent. of silicon—not a single rail had been broken. That was not a result from single samples, but from thousands. Those high silicon rails were all wearing well. But they had been rolled in single lengths, each from an ingot weighing a quarter of a ton. The same maker had been making say fifty thousand tons per annum for ten or fifteen years, with very good results in all parts of the world, and he was still continuing to use say 0·25 per cent. of silicon in his rail steel. Mr. Sandberg was therefore not afraid of silicon, but had every reason to leave silicon to the maker, and it was a great relief to himself not to have to analyze for silicon any longer. If the ingots were small, silicon was a benefit; but if they were large, it had better be avoided. Chemistry he believed would yet throw more light upon the manufacture of steel rails; but there was danger of its over-riding practical experience. Let

(Mr. Sandberg.)

chemistry explain what was obscure, and engineers would be glad of its explanations, but they did not wish to be ruled by it. Some years ago it had actually been understood that chemistry should be the ruler, and that the composition which it prescribed should be followed; and he knew of thousands of tons of rails having lately been rejected for such a reason as that the steel contained 0·07 per cent. of phosphorus instead of 0·06 per cent., even although the rails were intended for a hot climate. Certainly that was not right; it rendered steel rails unnecessarily dear. In such cases chemistry was out of place, and he hoped it would not assume a more prominent position than it occupied at present, which was quite enough for many rail makers as well as for the user.

With regard to the falling test, and Professor Arnold's remarks (page 339) on the tensile-test results in the paper, having enjoyed for thirty years the advantage of living in a practical country, he had learnt during that time to apply such a test as a material would be subjected to in actual work. For rails that test was not tension; it was impact and abrasion, as Mr. Head had rightly said (page 341). Therefore any testing apparatus for getting a quick result in regard to abrasion would be excellent. It had been proposed many times, but had not yet been carried out practically. In this respect he considered that the Underground Railway was the best testing machine; and breakage under a falling weight was another good test. At the Paris congress he had been much disappointed that the tensile test had not been discarded; it was a great trouble to engineers, and after all told nothing; yet it had been accepted by Mr. Werchovsky and other scientific men, who he considered were deceiving themselves in this matter. The tensile test cost an enormous amount of work, and he strongly urged its abandonment, keeping to the simple falling test, and getting as good a test as possible of abrasion.

The PRESIDENT proposed a vote of thanks to Mr. Sandberg for the valuable addition which he had made to the proceedings of the Institution; and in doing so he wished also to thank him cordially for the kind sentiments which he had expressed towards himself.

Mr. Thomas Urquhart, locomotive superintendent of the Grazi and Tsaritsin Railway, wrote that a recent circular issued by the ministry of railways in Russia requires all trains to reduce their speed on curves of less than 3,500 feet (53 chains) radius, in some proportion to the radius of the curve. On a perfectly safe straight line the maximum speed at which engines are allowed to run is in proportion to the diameter of their driving wheels and inversely to the stroke of the piston. Thus on most railways in Russia the diameter of the four coupled drivers of passenger engines is 5 feet 6 inches, and the maximum speed sanctioned by the government is 65 versts or 43 miles per hour; while on the Grazi and Tsaritsin Railway, the diameter of the driving wheels of the passenger engines being 5 feet 3 inches, the maximum speed is 62 versts or 41 miles per hour. The same maximum is allowed on curves of not less than 3,500 feet (53 chains) radius; but unfortunately the exact measure of the reduction of speed on sharper curves has been left an open question. As the resistance to traction on a curve increases by a percentage equal to the number of degrees subtended between the leading axle and the rear axle of the entire train, the writer recommends that the maximum speed should be reduced in the ratio of the difference of the angles subtended on curves of 3,500 feet (53 chains) and on curves of 2,100 feet (32 chains) radius, which latter are those mostly prevailing on the Grazi and Tsaritsin Railway. On curves of 2,100 feet radius this rule gives the following rates of reduction for the three classes of trains on the main line: passenger trains with engines having four wheels coupled, 7 per cent. reduction, to 57½ versts or 38 miles per hour; goods trains with six-wheel engines, 8 per cent., to 38½ versts or 25½ miles; goods trains with eight-wheel engines, 12 per cent. reduction, to 35 versts or 23 miles per hour as the maximum speed. The Russian railways are thus becoming awake to the necessity for great caution, especially on curves, where owing to the lightness of the rails hitherto used it is most difficult to keep the gauge perfect. The rails weigh only about 54 lbs. per yard, and are of the Vignoles section, with very weak fastenings to the transverse sleepers, which are spaced 30 inches apart from centre

(Mr. Thomas Urquhart.)

to centre. In maintenance of way the contrast is great between England and Russia; in the latter country a great number of men have constantly to be employed for keeping the spikes in their places, as the light rail by its vertical bending tends to work them out.

Mr. R. PRICE-WILLIAMS, being unable to attend the meeting, sent the following remarks.

In two important papers on the subject of the wear of steel rails, read last year at the International Railway Congress in Paris, there is much which would fitly supplement Mr. Sandberg's valuable paper. In one of those papers, by Mr. Louis De Busschere, engineer-in-chief of the Belgian State Railways, the conclusion arrived at by Mr. Couard, principal inspector of permanent way on the Paris and Lyons Railway, that the wear of hard steel rails is slower than that of soft steel rails, is adopted without any qualification; while in the other paper, by Mr. Bricka, engineer-in-chief of the French State Railways, the same opinion is expressed, with the important reservation "except in places where the brakes are skidded, or in tunnels." These views are entirely at variance, as Mr. Bricka mentions, with the previous conclusions arrived at by Dr. Dudley, Mr. Smith of Barrow, and the writer. While pointing out that the carbon alone does not suffice to render the metal both hard and slightly flexible, and that in order to combine both these qualities it is necessary for the steel to include a little silicon, Mr. Bricka admits that the Bessemer process, when the purest class of minerals are used, such as those of Bilbao, can alone give products which contain with a given proportion of carbon a slight and constant percentage of phosphorus and a sufficient quantity of silicon. The favourable results obtained by Mr. Werchovsky in the use of what are termed high-silicon steel rails are well worthy of attention. The conclusion however drawn by the author in page 307 from the series of his own independent experiments—namely that the hardness of steel rails is in no way affected by silicon, and that everything depends upon the percentage of carbon and phosphorus—does not appear to be justified by the results given in Table 2 from

his own experiments. From this Table it will be seen that the proportions of carbon and phosphorus certainly do not solely regulate the hardness of the rails experimented upon. For instance in test No. 15 there is as much as 0·38 per cent. of carbon, and a maximum of 0·07 per cent. of phosphorus, but with a small amount of 0·12 per cent. of silicon; while in strength and hardness, as measured by minimum deflection under a weight falling 15 feet, the rail stands ninth in order of precedence, having due regard also to the other mechanical features; in resistance to indent from a ton weight falling 5 feet it stands twelfth; in resistance to indent from a pressure of 50 tons it is about the average; and in tensile strength it stands only fifth. The maximum results obtained as regards tensile strength, and resistance to deflection and indent from falling and imposed weights, are met with in test No. 7, where the largest percentages of both carbon and silicon are combined with a minimum of phosphorus. Again in test No. 5, where the percentages of carbon and silicon and manganese are all high, and the phosphorus slightly higher, the rail broke under the impact of 1 ton falling 10 feet; the deflection under 1 ton falling 15 feet was as much as 2·28 inches, while the indent under a pressure of 50 tons was 0·24 inch; the tensile strength however was as much as 41·15 tons, the elongation was 18 per cent. in a length of 4 inches, and the percentage of contraction of the original section was about the average of the fifteen samples. On the other hand, in test No. 8, where the proportion of carbon is high, and that of silicon is a minimum, being only 0·08 per cent., the tensile strength is about the same as in the case of test No. 5, namely 41·46 tons, but the deflection and indent under the falling weight are higher. Finally in test No. 10, where there is a comparatively low percentage of carbon and manganese, but as much as 0·28 per cent. of silicon, the tensile strength is only 39·43 tons, while both the deflection and the indent from falling and imposed weights are rather above the average of the fifteen tests.

These variable results obtained from the high-silicon steel certainly do not appear to bear out the author's conclusion that silicon has no effect as a steel hardener; but on the contrary they strongly confirm Dr. Dudley's opposite contention. This becomes

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more evident if the total amount of steel hardeners in each of these fifteen high-silicon tests, and also in the three other samples of ordinary rails, are determined in terms of Dr. Dudley's phosphorus units, as given in the accompanying Table 4 (pages 356–357), which is a reproduction of the author's Table 2 with the addition of a column showing the sum of the four hardeners—carbon, silicon, phosphorus, and manganese—and also a column of Dr. Dudley's equivalent phosphorus units, one phosphorus unit being 0·01 per cent. of phosphorus; the maximum * and minimum § results are also marked throughout the Table; and the mean is inserted for the fifteen tests of Bessemer high-silicon steel.

It will be seen that in nearly all cases the results thus expressed in Table 4 in terms of phosphorus units are entirely consistent, and in accord with the results of the mechanical tests. For instance the maximum hardness measured in phosphorus units, namely 55·8, is met with in test No. 5, where the rail broke under the impact of 1 ton falling 10 feet, and where the small amount of indent from the other falling and imposed weights, together with the slight percentages of elongation and contraction, equally testify to the exceptionally hard quality of the steel, which contains nearly the highest percentage of silicon, namely 0·27 per cent. The next hardest in the scale of phosphorus units is test No. 7, with 53·7 units; in this test, as already pointed out, there is a maximum of 0·41 per cent. of carbon and 0·28 per cent. of silicon, with only about the average of manganese, namely 1·00 per cent.; and here the maximum tensile strength, 54·86 tons, is combined with nearly the smallest deflection under the falling weight, and the smallest amount of indent under both falling and imposed weights, and also with the minimum elongation and contraction. Most of the other phosphorus-unit estimations will be found to be in accord with the results obtained by the mechanical tests.

In drawing attention in his paper to the great and very variable amount of wear in steel rails at the present day, Mr. De Busschere alludes to the hope expressed in a paper † read by the writer on this

† "On the Permanent Way of Railways." Proceedings Institution of Civil Engineers, 1876, vol. xlvi, pages 165, 200, and 204.

subject fourteen years ago, that with the knowledge then possessed the steel rail manufacturers would for the future be able to produce rails whose enduring quality would equal at least the best made at that time; and he says that this hope has not yet been realised. This the writer admits; and also, what is more, that the large experience since acquired in regard to the wear of steel rails, so much dwelt upon at the Paris congress, as well as these results of Mr. Sandberg's experiments, only tend to prove that engineers are yet a long way from having obtained a sufficient knowledge of the exact proportion of the chemical constituents which are required to render a steel rail at once the strongest, the most enduring, and the least liable to fracture. One thing at least however is clear: that, while recognising the beneficial effects in the manufacture of steel rails, resulting from high percentages of silicon, to which Mr. Sandberg has drawn timely attention, silicon cannot be expected entirely to convert bad material into good; and it is well to bear in mind what Sir William Siemens so forcibly pointed out during the discussion upon the writer's paper, namely that if steel was produced from pure iron, such as was found in Sweden, a metal could be made, containing hardly any manganese and only a trace of carbon and no appreciable percentage of silicon or phosphorus, which was as nearly as possible pure iron, and was perhaps the toughest that could be made. That steel rails of the high enduring quality that characterised those to which the writer drew attention fourteen years ago can be made, and are still being made, is undoubted; and is proved by the profile of two 80 lbs. steel rails, laid down on the Great Northern Railway 8½ years ago, one between the 34th and 35th mile-posts on the ascending gradient of the down fast main line, and the other on a descending gradient of 1 in 660 on the up fast main line, between the 55th and 56th mile-posts; these have worn only about 1-16th of an inch in that time. Allowing only 3-8ths of an inch as the uniform wearing depth of these rails, this would give at least 51 years as the measure of their life. These rails however, the writer understands, were made from the best hæmatite iron; but what the chemical constituents are he has not been able to ascertain. In page 301 of the paper the author expresses the opinion that the mechanical hardening of steel rails has

TABLE 4 (*continued on opposite page*).

Bessemer Steel Rails containing high percentage of Silicon.

Rearrangement of Table 2, page 324.

Chemical Test of Elements.

Description of Steel.	No. of Test.	CARBON. 3 Carbon units = 1 Phosphorus unit.	SILICON. 2 Silicon units = 1 Phosphorus unit.	PHOSPHORUS.	MANGANESE. 5 Manganese units = 1 Phosphorus unit.	Sulphur.	Total Hardeners: Carbon, Silicon, Phosphorus, and Manganese.	Phosphorus Units.	Order of precedence of Phosphorus Units.
Bessemer High Silicon Steel.	No.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	Units.	
	1	0·36	0·13	0·06	1·00	§0·05	1·55	44·5	13
	2	0·36	0·15	*0·07	0·97	0·06	1·55	45·9	11
	3	0·35	0·26	*0·07	1·02	0·06	1·70	52·1	3
	4	0·36	0·27	0·06	0·96	0·06	1·65	50·7	6
	5	0·36	0·27	0·065	*1·19	§0·05	*1·885	*55·8	1
	6	0·31	0·26	0·055	1·06	0·06	1·685	50·0	7
	7	*0·41	*0·28	0·06	1·00	0·07	1·75	53·7	2
	8	0·37	§0·08	0·06	§0·88	0·06	§1·39	§39·9	15
	9	§0·26	0·23	*0·07	0·92	§0·05	1·48	45·6	12
	10	0·28	*0·28	§0·05	0·90	*0·08	1·51	46·3	10
	11	0·32	0·25	0·06	1·12	0·06	1·75	51·6	4
	12	0·29	0 26	*0·07	1·07	§0·05	1·69	51·1	5
	13	0·32	0·22	*0·07	0·92	§0·05	1·53	47·1	9
	14	0·31	0·27	0·06	0·96	§0·05	1·60	49·0	8
	15	0·38	0·12	*0·07	0·94	0·06	1·51	44·5	14
Mean		**0·34**	**0·22**	**0·06**	**0·99**	**0·06**	**1·61**	**48·1**	
Bessemer Ordinary.	16	§0·35	0·06	*0·06	§0·80	0·07	§1·27	§36·7	
	17	*0·42	§0·05	*0·06	*1·00	0·07	*1·53	*42·5	
	18	0·40	*0·07	§0·05	0·92	0·07	1·44	40·2	

* Maximum. § Minimum.

(*concluded from opposite page*) TABLE 4.

Bessemer Steel Rails containing high percentage of Silicon.

Rearrangement of Table 2, page 325.

Mechanical Tests of Strength and Hardness.

TRANSVERSE IMPACT.	HARDNESS TESTS.			TENSILE TEST.			
Impact of 1-ton ball falling 15 feet on rail 80 lbs. per yard. Bearings 3 feet apart.	Impact of 1-ton ball falling 5 feet on blunt cone with small end 1 inch diam. placed on rail head.	Impact of 1-ton ball falling 10 feet on sharp-pointed cone placed on rail head.	Pressure of 50 tons on sharp-pointed cone placed on rail head.	Breaking Strain, tons per square inch.	Percentage of Elongation in length of 4 inches.	Percentage of Contraction of original section.	No. of Test.
Deflection in centre.	Depth of Indent.	Depth of Indent.	Depth of Indent.				
Inches.	Inch.	Inch.	Inch.	Tons.	p. c.	p. c.	No.
§1·89	*0·24	*0·87	0·24	38·86	*23	43	1
2·05	*0·24	0·79	0·24	39·68	20	38	2
2·20	0·20	0·71	0·24	47·50	17	34	3
2·05	0·20	0·67	0·24	49·84	14	30	4
2·28	§0·16	Broke.	0·24	41·15	18	35	5
2·20	§0·16	0·67	0·24	40·64	19	37	6
1·93	§0·16	§0·63	§0·20	*54·86	§ 8	§ 8	7
2·56	0·20	0·71	0·24	41·46	18	*47	8
*2·95	*0·24	0·79	*0·28	§35·11	*23	33	9
2·60	*0·24	0·75	*0·28	39·43	14	31	10
2·36	0·20	0·71	0·24	45·40	18	32	11
2·68	*0·24	0·71	*0·28	40·64	21	36	12
2·60	*0·24	0·75	0·24	40·45	22	31	13
2·48	*0·24	0·79	0·24	40·06	*23	34	14
2·36	*0·24	0·79	0·24	43·50	16	26·5	15
2·35	**0·21**	**0·74**	**0·25**	**42·57**	**18**	**33**	M
*2·09	*0·22	*0·79	*0·26	§37·34	*22	*34	16
§1·89	§0·20	§0·71	§0·24	*46·61	18	33·5	17
1·93	§0·20	*0·79	§0·24	44·32	§17	§22·4	18

* Maximum. § Minimum.

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largely been done away with at the present time by the direct process of making steel and by quick-running mills, and that chemical hardening has therefore to be relied upon. He further speaks of the average life of a steel rail as being only about three times that of an ordinary iron rail (page 308). Now an iron rail on the Metropolitan Railway, as the President pointed out fourteen years ago, had then only an uncertain life, ranging from a few weeks to about one year; and the life of an iron rail on the main lines of our principal railways would at present, with the much heavier trains and higher speeds, be very little more. If therefore the rails in such situations can only be counted upon to last so short a time as three years, the employment of such a class of steel rails could not be justified, having regard to the great risks and dangers incidental to frequently breaking up the road. The advantages of their being so cheaply made as at present are very questionable, and everything points to the growing necessity for using, for the heavy main-line traffic at least, only the very best and purest iron that can be got, with a return to the slower rolling of former years.

With what the author says as to the great advantages of adopting heavier sections of rails generally, and the great economies resulting therefrom, the writer entirely concurs; and from his own experience he can testify that the rapid failures he has recently observed of many steel rails in the colonies are mainly due to their being too light, and to the absence of good hard stone ballast, and to the neglect of proper drainage and maintenance of the way.

Great credit is due to the author for having carried out these interesting and independent experiments. The subject is a most vital one, largely affecting as it does not only the great railway interests, but also the interest and welfare of the public generally. With the large amount of valuable data now possessed in regard to the wear of steel rails on most of the principal main lines of railway in this country, extending over a period of nearly thirty years, and with records in most cases of the amount and the speed of the traffic which has passed over the rails, much additional light might be thrown upon the still obscure causes of the unequal and very variable wear they continue to exhibit. These investigations however

are much beyond the power or at least beyond the means of any individual; and the writer would suggest that the subject is one which, in the interests of this Institution and of engineers generally, might with advantage be entrusted to the Research Committee of the Institution.

ON RECENT IMPROVEMENTS IN THE MECHANICAL ENGINEERING OF COAL MINES.

By Mr. EMERSON BAINBRIDGE, of Sheffield.

In the management of Collieries, it may be safely asserted that the science of mechanical engineering is as important as mining engineering; and as coal has now to be worked at greater depths than formerly, and from greater distances underground, the application of suitable, effective, and economical machinery becomes more and more important. Thirty years ago a considerable quantity of coal was produced from pits near the outcrop of the various coalfields in the United Kingdom, and few collieries were raising such a quantity as 600 tons a day. At the present time, winding from depths of 700 or 800 yards, and hauling a distance of two miles underground, are conditions which are not unusual; and no mining engineer will open out a large coalfield with a view of raising a less output than 1,000 tons per day.

The intention of the author is to describe briefly some of the chief mechanical improvements, which have been devised to meet this altered state of things and to effect economy in the production of coal. The subject may be considered under the following heads:—

1. Sinking Shafts.
2. Pumping.
3. Winding Coal.
4. Production of Steam.
5. Haulage of Coal.
6. Coal Getting.
7. Ventilation of Mines.
8. Screening and Cleaning Coal.

1. Sinking Shafts.

The over-production, which took place in consequence of the large amount of capital expended in new coal winnings immediately after the inflated times of 1872 and 1873, caused the supply of coal to exceed the demand, and as a consequence very few pits have been sunk during the past twelve years. Hence there has been little change in this branch of mining; but several new arrangements connected with the sinking of pits may be of interest.

Freezing process.—In Germany a number of successful sinkings have been carried out by the Poetsch freezing process, which is of special service in cases where sinking has to be carried on through quicksand, and through a large quantity of water; and the process in this respect appears to have advantages over the Kind-Chaudron plan. Briefly Mr. Poetsch's system is to drive down freezing tubes through quicksands, eighteen tubes being used where a shaft was sunk of 11 feet diameter. These tubes are 6 inches diameter, and each contains an inner tube of 2 inches diameter, through which the freezing liquid descends, returning upwards through the annular space between the two tubes. As soon as the ground is frozen to the extent of an estimated radius of about 10 feet beyond the pipes, the shaft is sunk in the space within the tubes. The work has to be done by pick and drill, no blasting being permissible for fear of breaking the freezing tubes or the frozen casing. Attempts have been made to thaw out the frozen core in the centre of the shaft by steam jets, and by a boring apparatus; but these were found cumbrous to work, and produced a soft mud, into which the miners sank up to their knees.

Great depths.—In cases where the sinking of pits is carried to considerable depths, the hoppet or trunk which brings out the material excavated is usually brought up without guides. With the object of steadying the trunk and thus getting a greater speed, Mr. W. Galloway of Cardiff has designed an arrangement for carrying on sinking and walling simultaneously in a shaft, by means of guide ropes from which the walling scaffold is suspended; and several

pits have been successfully sunk by this process. In this plan two steel wire guide-ropes, attached to the walling stage in the shaft, pass over pulleys and are coiled upon the drums of a screw steam crab at some distance from the shaft; these drums can be worked simultaneously or separately for lowering and raising the stage. A rider sliding upon the ropes consists of three principal pieces of iron, namely: a cross bar in which there is a central opening 3 inches diameter, through which the winding rope runs loosely; and two vertical legs bolted to the cross bar, having two openings of 2 inches diameter for the guide ropes to pass through. A circular iron plate 6 inches diameter rests horizontally on the cap at the bottom end of the winding rope, and supports an india-rubber buffer 6 inches thick. The bottom extremities of the guide ropes have similar buffers, 4 inches diameter and 4 inches thick. The guide ropes are 5 ft. 6 ins. apart centre to centre. The walling stage is permanently suspended in the shaft by the guide ropes, and is of wood supported on an iron frame, and has a central opening 6 ft. 6 ins. square, through which the trunk can pass. At 10 ft. 6 ins. above the stage there is a similar construction called the roof, having an opening 5 ft. 6 ins. square; an iron ladder provides a means of access from the stage to the roof. When the end of the winding rope is raised above the walling stage, the rider is caught up by the buffer, and slides on the guide ropes; and when the end of the rope passes below the stage, the rider is left standing upon the buffers at the bottom of the guide ropes, while the trunk can be lowered to the bottom of the shaft.

Mr. Galloway has also adopted in South Wales a pneumatic water barrel for raising the water from the bottom of sinking pits, and saving the laborious and expensive mode of baling water into the trunk. The pneumatic barrel, when it reaches the bottom of the pit, is attached by an instantaneous coupling to a pipe, which passes down the shaft from an ordinary air-pump condenser constantly working upon the surface. The water is sucked into the barrel by means of a flexible hose, the height of the water being noted by a glass water-gauge. In this manner the water barrel is filled in about half a minute. By this process a sinking was taken down,

where 5,000 gallons of water per hour had to be contended with, at the rate of five yards a week; previously the same speed only was maintained with a feeder of not more than 500 gallons per hour.

Explosives.—In the use of explosives for sinking purposes, considerable advantage has been derived from firing a number of shots simultaneously by means of an electric battery, the effect being to obtain an accumulated force, and to reduce the amount of time lost by firing separate shots, and by missed shots.

Little progress has been made in the application of power drills for sinking shafts, it being found that sinking is carried on with almost equal advantage by hand as by machine, except in cases where very hard rock is met with. Schram's percussive drills are being used successfully in the tunnels forming part of the railway between Sheffield and Chinley; and have also been used in the sinking of a shaft by the Parkside Mining Co. In the latter case the drills were mounted on horizontal telescopic stretcher-bars, jammed between the walls of the shaft. These bars required only one setting for each round. The position which best suited for them was 20 inches from the bottom of the shaft, and this height allowed each row of holes to be bored at the requisite angle or pitch. Two machines were used, one on each bar; and each drill bored two or three rows of holes, each hole being from 5 feet to 7 feet deep. The number and depth depended upon the nature of the rock, whether free-shooting or otherwise. The sump was kept in the middle of the shaft; and the four centre-cut holes forming it were fired first and simultaneously by electricity. The remaining holes were fired by ordinary fuse, one hole liberating the other in the usual manner. The time required for taking down the drills, setting them, and boring the holes, and also for removing the gear, was from two to four hours. The firing of the holes and clearing out of the debris from the blasting occupied about sixteen hours; and the depth cut with each round of holes ranged from 5 feet to 7 feet. The speed attained in sinking with the machines was from $3\frac{1}{2}$ to 4 times that of hand work; and setting aside the cost of producing the compressed air, and any charges for first cost or depreciation of machinery, and

taking into account only labour and explosives, the cost by machine was £9 12s. per fathom as against £12 by hand.

2. Pumping.

Under the head of pumping, reference may be made to the development of one department of colliery management which is often beset with many difficulties, namely underground pumping. Having tried for this purpose at a number of collieries the Parkin and Weston pump, the author thinks it right to state that, after years of experience of its working under many various conditions, it has proved itself one of the most satisfactory to deal with for underground pumping. It consists of a direct-acting compound engine, having the steam cylinders placed horizontally one behind the other, with a piston-rod common to both, which is also connected with the pump piston in the same line. The special feature of the pump is its non-liability to get out of order.

Another process of pumping by hydraulic power has been introduced by Mr. Moore of Glasgow, in which water is used for the purpose of transmitting power from the steam engine to the pump. The water is contained in pipes connecting the engine with the pump, and vibrates backwards and forwards in the pipes, thereby giving the pump a reciprocating motion similar to that of the engine; the water thus acts practically as a mechanical connection like a rigid coupling-rod.

The mode of dealing with the large quantity of water often met with in sinking pits has always been a matter of great importance, because of the following obstacles which have to be overcome:—first, the trouble of having constantly to lower the pumps, together with a consequent lengthening of the spears or rods; second, the difficulty of keeping the valves and working barrels in order, in consequence of the quantity of solid matter which is necessarily raised with the water; and third, the difficulty of carrying on sinking work with pumping appliances always at the bottom of the pit.

A form of sinking pump recently designed by Messrs. Bailey and Co. of Salford, Fig. 1, Plate 121, is now successfully at work at the

Cadeby new winning in South Yorkshire, and contends with the above difficulties in a very satisfactory manner. The pumps are hung in the shaft by wire ropes from the surface, and are easily lowered by means of powerful capstans as the sinking progresses. The special feature of this steam pump is that, instead of having an engine, with foundations, connecting-rod, quadrant and spears, all liable to wear and tear and mishap, the combined engine and pump is the only thing to be dealt with. Eye-bolts are provided at the top, by which it is suspended from chains or wire ropes, and lowered to follow the falling water. The pump consists of three hollow plungers. The upper pair A A are stationary, and surrounding them are sliding barrels B B, which are connected to the steam piston P. From the lower end of these barrels projects the bottom plunger C, double the diameter of the upper pair, and working into the third barrel D, which latter is secured by means of connecting-bolts to the steam cylinder. Thus there are two smaller barrels B B on the top of the larger ram C. There is a group of valves opening upwards in the junction between the smaller barrels and the larger ram, constituting the delivery valves; and another group of valves opening upwards at the bottom of the larger barrel D, constituting the suction valves. The action of the pump is as follows. As the bottom plunger rises, the water follows it up into the lower barrel D; at the same time the water in the upper barrels B B is forced up into the rising main M. In the down stroke, the water in the lower barrel D is forced up through the lower hollow plunger and delivery valves into the upper barrels and plungers, and thence into the rising main. Thus there is a continuous delivery in the up and down strokes. One of the upper plungers is open on the top, and forms the discharge orifice for the water into the rising main; and the other is closed, forming an air-vessel V, which is continuously charged with air through a suitable snifting valve fitted to the side of the pump nearest to that plunger, and below the delivery valves; this snifting valve permits a small quantity of air to be drawn in with every upstroke of the pump. The steam cylinder is fitted with the Davidson slide-valve. Six of these pumps have been supplied to the Denaby Main Colliery,

near Doncaster, and will together raise 300,000 gallons per hour through 300 feet. Each pump has its own winding drum and steel-wire rope, enabling each or all of the pumps to be raised or lowered at will. Two shafts are being sunk to a depth of 600 yards, and four pumps are in one shaft and two in the other. Each pump has a telescopic suction-pipe, which enables a depth of 9 feet to be sunk without lowering the pump.

A pumping engine of similar construction, known as the Straight-Line pump, is fixed at the Stanley Coal Co.'s colliery.

One difficulty in pumping in a sinking pit arises from the necessity for continually adding to the length of the rising main as the sinking goes down. This work is generally done at the bottom of the rising main; but a simple method has been devised by Mr. Hewitt whereby it is done at the top of the pit. A delivery pipe or nozzle, rather longer than one of the pipes forming the rising main, is inserted through a stuffing-box in the topmost pipe of the rising main; the latter goes down with the pumps as they are lowered, and the stuffing-box slides on the delivery nozzle, which remains fixed. When the stuffing-box gets low enough, the topmost pipe is unbolted and raised, sliding up on the delivery nozzle; and another length of pipe is added beneath it, for lengthening the top of the rising main. In this way the inconvenience of having a sliding suction-pipe at the bottom of the rising main is obviated.

Coupling for Broken Pipes.—Owing to the liability of accidents through falls of roof, difficulties with haulage, and upheavals, there is frequently considerable trouble with the use of metal pipes underground; and it is important to adopt the best means of quickly repairing broken pipes. A process that has been used for some years in collieries with which the writer is connected is shown in Fig. 2, Plate 121. If both flanges are broken at a joint, or if a breakage takes place at the middle of the pipe, the loose flanges A A are slipped on to the pipe, and then the short tube B between them; the two flanges are then both bolted together, and perfect tightness is obtained by inserting india-rubber rings at I I. If

only one flange is fractured, only one ring A is used, which is bolted to the sound flange with the short tube B between.

The same object has been aimed at in a joint which is manufactured by Messrs. Howell and Co. at their steel tube works in Sheffield, as shown in Fig. 3, Plate 121. This joint is suitable for steam, water, or compressed air, and can be made to suit any size and thickness of piping. The joint itself is made outside the piping, thus reducing the risk of pieces of the packing material being drawn into the pipes.

Petroleum Engine.—The petroleum engine has come into use lately, and is driven by the same method as an ordinary gas engine. Petroleum is forced into a cylinder as spray, and is there volatilised by the heat from the working cylinder, and is exploded by an electric spark from a small storage or other cell. The oil used is about $1\frac{1}{4}$ to $1\frac{1}{2}$ pints per actual horse-power per hour. One of these engines, brought out by Messrs. Priestman Brothers of Hull, is now at work in the Nunnery Colliery at a distance of a mile and three quarters from the shaft, and is pumping about 40 gallons per minute through pipes 1,700 yards in length to a vertical height of 400 feet. It has not been long enough at work to prove its cost; but there is no doubt as to its being a very convenient arrangement. At another colliery, where it has been working for about two years, the cost for labour, paraffin &c., has been found to amount to $1\frac{3}{4}d.$ per horse-power per hour, the paraffin costing about $\frac{3}{4}d.$ per indicated horse-power per hour. The only risk in the use of the engine lies in having in the pit such a mineral oil as petroleum, and in the heat which is produced in the warming of the engine before its working is commenced; but to meet the circumstances of the case a protecting arrangement has been designed on the principle of the safety-lamp. At the Nunnery Colliery four of Grinnell's sprinklers have been attached to the rising main in the petroleum-engine house; and these will bring the whole pressure of water in the column into the engine-house in the form of a douche, if the temperature in the house is raised by any accident up to 155° Fahr. The action of the sprinkler depends upon the

heat melting a soldered joint, thereby liberating the cap which closes the nozzle, and so allowing the water discharge to take place. The advantage of this mode of pumping underground, over the modes of transmitting power by ropes, rods, compressed air, and electricity, lies in having the motive power directly at the pump.

3. Winding Coal.

Guides.—The winding of coal from deep mines is a matter of great importance, as any loss of time is apt to affect seriously the output of a colliery. The old system of wooden guides is quickly giving place to wire-rope guides, of which two, three, or four are employed. An arrangement for applying these guides, in a manner which enables the cages to run at a minimum distance from each other without risk, is adopted at a Staffordshire colliery where the cages pass each other at a distance of only $3\frac{1}{2}$ inches apart. Three guide ropes are fixed on the outer side only of each cage, and run in thimbles attached to the cage; and between the two cages two more guide ropes are hung, to prevent the cages from touching each other; these two guide ropes are not connected with the cages at all. It is found that the cages rarely touch these inner guides; where the ropes hang, the sides of the cages are bushed with brass.

Another mode of enabling cages to run close together is by adopting steel rails as guides. This plan is used at the Nunnery Colliery, but is not to be recommended. Like the wooden guides, the steel rails cause some obstruction in the shaft, and the first cost is considerable; besides which there is serious wear, both of the rails and of the guides on the cages, if the least error in the perpendicularity of the cages takes place.

The four special points which require attention in dealing with the winding of coal are:—speed in winding; economy of fuel; quick changing of tubs; and wear and tear of ropes and cages.

Speed in Winding.—A number of endeavours have been made to obtain a combination of swift winding and economy of fuel by adopting automatic variable cut-off gear; but this is now in use at very few collieries in this country. Guinotte's gear has been

successfully applied at the Blackwell Colliery in North Derbyshire; and whilst it is very effective in saving fuel, it somewhat retards the swift winding of coal.

Counterbalancing.—A good deal of attention has been paid to the counterbalancing of the full cage and the rope attached thereto. This has been done in the three following ways:—firstly, by a counterbalance weight working in a small shaft or staple, or running on a steep incline; secondly, by using a scroll-drum with varying diameters; and thirdly, by attaching to the bottom of both cages a rope, about equal in length and weight to the winding rope.

The first process was largely used some years ago in the North; and it is somewhat singular that, in the large winding plants put up in the last twenty years, provision has seldom been made for counterbalancing. With regard to scroll-drums, their great weight often counteracts their useful effect; and, as far as the author knows, no drum has yet been made combining lightness with a sufficient difference between the smallest and largest diameters to constitute a thoroughly effective counterbalance. A drum designed to provide very fair conditions of counterbalancing is at work at the Ynysybwl Colliery, and varies in diameter from 18 feet to 33 feet; the depth from which coal is drawn is 500 yards, and the winding occupies 35 seconds.

The hanging counterbalance rope has come into use during the last fifteen years, and is simple and effective. The objections to it are that it contributes a new danger in the shaft in case of accident, and adds to the load upon the winding rope; but considering the way in which it economises fuel and promotes the speed of winding, it is remarkable that it has not been adopted upon a larger scale.

As illustrations of swift winding, it may be mentioned that at a colliery in North Derbyshire during the first week in June 6,309 tons were raised from a depth of 509 yards, the time of winding being from 7 a.m. to 3.30 p.m. At two other Derbyshire pits, 170 and 140 yards in depth, the speed of winding and changing has been brought to such perfection that tubs are drawn and changed three times in one minute.

On the continent an arrangement for winding, known as the Koepe system, has been adopted, but it has been used at only one colliery in this country. In this plan, shown in Fig. 5, Plate 122, the large winding drum is replaced by a pulley P, thus saving a considerable amount of dead weight, and consequently of first cost. The hanging counterbalance rope C below the cages is here used. The winding rope R always works in a straight line with the pulley wheels WW, and it is not found to slip on the driving pulley P. But this pulley requires considerable maintenance, and the cost of ropes is certainly higher where this mode of winding is adopted. A smaller winding engine will do the work with this system than with the ordinary drum ; but if a rope breaks, there is a likelihood of both cages falling to the bottom.

Compound engines for winding have been adopted to a limited extent.

Economical Banking.—In coal-winding, when a large quantity is drawn, a few seconds more or less in taking the full tubs from the cage at the pit top, and replacing them by empty ones, has a serious effect upon the work of the day. In recent years several improvements have been made in this respect.

Where a cage has only one deck, the quick changing of the tubs is easily accomplished. Where there are two decks, and these are lifted by the winding engine from one level to another whilst being emptied, there is both loss of time and wear and tear of the winding rope. A very common mode of meeting this difficulty is to provide arrangements at the top of the pit for emptying both decks simultaneously. This is done by having an extra platform above the main bank level; and whilst the cage is being sent down the pit, the two full tubs which have been placed upon the upper platform are dropped down to the bank level by counterbalanced cages, which at the same time hoist up the empty tubs into position. Where however there are three decks, this is not so easy to carry out; but at a colliery in North Derbyshire arrangements are being carried out to empty all three decks at once, and to bring all the tubs to one level during the winding.

With regard to changing tubs, it is of course understood that special power is required to push the full tubs out of the cage, and replace them by the empties; and various arrangements have been devised to reduce the manual labour required, two of which may be mentioned. In Mr. Fowler's plan the tubs are pushed out of the cage by small hydraulic rams; and the method works swiftly and economically, but has been adopted only upon a small scale hitherto. In Mr. Fisher's plan, the empty tubs intended for the cage on its arrival at the surface are placed upon a movable platform, of which the end furthest from the pit is raised by a small steam cylinder, thereby tilting the tubs into an inclined position immediately the cage reaches the surface and drops upon the keps. This sets in motion the empty tubs, which then get enough impetus to push the full tubs out of the cage. This arrangement works very satisfactorily, and may be seen at the Clifton Colliery, near Nottingham. A similar idea has been carried out by the writer in the construction of a cage at Nunnery Colliery, Fig. 7, Plate 122, which however is not yet put to work. The rails on which the tubs rest in the cage are hinged at one end, and when the cage reaches the top of the pit, and is lowered upon the keps, the other end of the rails is tilted upwards by the nose of the kep projecting above its catch, thus enabling the full tubs to run out easily.

A general difficulty in banking coal, which has not been properly dealt with until the last few years, arises from the fact that the empty tubs have to be put into the cage on the same level as the full tubs; and as the full tubs ought to have a fall to the screens of about 1 in 60 in order to run freely, it follows that, if they have to go a distance of 10 to 20 yards in order to get into position before going down the pit again, they have to be taken up hill. This point is now dealt with by mechanical creepers, which, by means of small lugs projecting up to the tub axles, push the empty tubs into such a position that before entering the cage they can rest upon rails inclined towards the shaft; and thus no labour is required to get them into position. The writer has adopted this plan with success at several collieries in the midland counties. It is part of a general system of banking at the Kibblesworth Colliery, which for a limited

output may be regarded as a very complete and economical arrangement.

A mode of holding back the empty tubs, when resting on a slight incline preparatory to passing into the cage, is shown in Fig. 6, Plate 122; by means of a treadle the tubs are set free, and run into the cage.

A contrivance introduced by Mr. W. Galloway of Cardiff, for regulating the speed of tubs descending an incline to the pit bottom, consists of a pair of long oak brake-beams, parallel with the rails, one on each side of the line, having a projecting angle-iron along their inner face; their upper ends are hinged to uprights at about the level of the top of the tub wheels; and their lower ends, which droop about 4 inches nearer to the rails, rest upon props, and are nearly counterbalanced by weights suspended over pulleys. The wheels of the tub entering at the upper end wedge themselves between the rails and the brake-beams, and would at once lift the beams and pass through without their velocity being materially reduced, were it not that the lower end of each brake-beam is controlled by a dash-pot, or cylinder filled with water and having a piston working loosely in it. While presenting little resistance to a slow movement, the dash-pot so checks the lifting of the brake-beam as effectually to regulate the speed of the tub to any velocity required.

In referring to different modes of emptying cages, mention should be made also of the pit bottom, where of course equal despatch is necessary. In some cases it is difficult to arrange for several landings underground, and in others it is a convenience to have the coal brought out on two different levels. In cases where only one landing is available, the arrangement in vogue at a West Yorkshire colliery is found to act very satisfactorily. This is shown in Fig. 23, Plate 125, and consists of a movable platform P, large enough to hold both cages, which is suspended in the sump by means of two ropes coiled round separate drums; upon the drums are hung counterbalance weights W for the purpose of raising the platform P again to the level of the landing, after the cage has started on its journey up the shaft. A powerful brake on the drum is under the control of the onsetter, who lowers the cage into the sump, deck by deck, as it is charged. The advantages of this method are:—firstly, an

important saving of time, as the changing at the shaft bottom is done independently of that on the surface; secondly, prevention of strains upon the winding rope, such as would be occasioned by raising the bottom cage during the changing; thirdly, saving of steam; and fourthly, economy of labour compared with that needed for double landings.

Springs for protecting Cages.—Another point to be considered in the winding of coal is the wear and tear of ropes and cages; and various attempts have been made to reduce this, either by putting india-rubber under the journals of the winding pulleys, or by interposing rubber or springs in the connection between the cage and the rope; also by allowing the cage to drop on india-rubber or old hemp rope at the pit bottom. The pulley wheels at the Nunnery Colliery rest in this way on rubber, which however is practically of no service, as it so soon becomes hardened.

At two of the Nunnery Collieries an effective plan has been adopted, which saves the wear of cages, by reducing the shocks upon the rivets, and prolongs the life of the ropes, whilst at the same time it gives some assistance to the winding engine. It consists simply of four strong spiral springs, upon which the cage rests when it reaches the bottom of the shaft. These have been at work for a period of eight years. In the ordinary winding of coal, the bang of the cages at the pit bottom is a familiar sound. Where these springs are employed, this is entirely obviated. The depression of the cage when it reaches the pit bottom is about two inches, which is reduced to about one inch when the cage steadies, but increases again to two inches when the full tub takes the place of the empty one. When the cage is ready to be drawn up the shaft, the compressed springs below it contribute a certain propelling power the moment the rope is taut; and in this way the first strain upon the winding engine is to a certain degree relieved.

4. Production of Steam.

It is sometimes thought that the question of economy of fuel at collieries is not of much moment, and it may be supposed that there

is not much information to be acquired by mechanical engineers from what is done at coal mines in the production of steam; but there are certain difficulties with which the managers of collieries have to deal, from which perhaps some useful lessons may be learnt. Where no coke ovens exist, the consumption of fuel at a colliery varies from 2 per cent. to about 10 per cent. of the output; and roughly speaking, this is equivalent, as part of the general working cost, to a cost per ton varying from $\frac{1}{2}d.$ to $3d.$ per ton, the variation being due to the class of boiler used, to the amount of pumping and haulage required, and to the selling value of the coal used for colliery consumption. Two special difficulties at a colliery are bad feed-water, and the need of utilizing inferior coal for boiler purposes. The latter point had to be considered in the case of the Nunnery Collieries, where six years ago new boiler plant was put down, which now constitutes one of the most complete and economical installations in the district. Without going into details, it may be briefly stated that the plant presents the following special features.

Firstly, the coal used is of a very inferior quality, and is scarcely fit for sale, containing as it does so much ash and impurity; and hand-firing was found to be almost impossible. Experiments were therefore made with a number of mechanical stokers. The machines tried were those known by the following names:—Bennis, the Helix, Hodgkinson's, Whittaker's, and Proctor's. After a series of careful trials, Proctor's stokers were applied four years ago to a group of seven Lancashire boilers, and are now working satisfactorily. These boilers consume about 60 tons of coal per day, yielding about 10 tons of ash and refuse. The Proctor stoker throws the fuel upon the fire-grate at various points.

Secondly, the ash &c. when drawn from the fire-place is apt to damage the front of the boiler, which is therefore protected by an iron apron made in one piece.

Thirdly, the boilers are set in a somewhat unusual way, the side flues being made larger than usual, and fitted with doors for enabling the boiler sides to be easily swept. The return gases are allowed to impinge upon the sides of the boiler to a height of 12 inches above the water line.

Fourthly, an economiser is placed at the back of the boilers, which consists of 350 tubes; and the gases leave the boilers at a temperature of about 400° Fahr., and reach the chimney at a temperature of about 280°.

Fifthly, the feed water is passed into the economiser by an exhaust injector, and reaches it at a temperature of 170°, leaving it at a temperature of about 280°; but the latter temperature varies when there is any incrustation within the economiser.

In cases where mechanical stokers are used, and where the coal can be supplied from hoppers above them, a carrier or endless belt is sometimes employed. In a scheme devised for utilizing such a carrier, the small coal for the boilers is taken slowly over the tops of the coal hoppers by the endless belt, filling each with coal. The same carrier passes down below the level of the floor in front of the boilers; and through a hole in the floor the ash from each boiler drops upon the returning belt, by which it is conveyed to a hopper or elevator. The same carrier is thus used for taking coal in one direction, and for bringing ash away in the other. The same work might be done by the adoption of two separate worms.

The mode of dealing with impure and deleterious water for boilers has undergone very little improvement in the last twenty years. Two important points have to be aimed at, namely:—(1) if the water contains a certain quantity of solid matter which precipitates on boiling, it is of little use trying to prevent this, and it is sufficient to endeavour to prevent the deposit from incrusting the various parts of the interior of the boiler, unless it can be precipitated before the feed water enters the boiler: (2) it is equally important to prevent the water used from corroding the inside of the boiler; and where a so-called boiler composition succeeds in softening the scale, it is liable to fail in preventing corrosion. At the Nunnery Company's Woodthorpe Colliery the scale has been kept soft by a contrivance known as Bower's separator, consisting of an external depositing-box, through which, by means of a vertical diaphragm coiled inside, the boiler water is caused to circulate slowly in a long spiral course, allowing ample time for the sediment to settle down to the bottom of

the box, whence it is blown off periodically. The flow through the separator takes place by natural circulation, consequent upon the difference of temperature between the hotter water entering the box from the boiler, and the cooler water returning from the box to the boiler.

Sufficient importance has not been ascribed, the writer believes, to the adoption of thin plates in steel boilers. Thirteen years ago, for a set of boilers for a colliery in Nottinghamshire, he adopted plates only $\frac{1}{4}$ inch thick, and these are working at the present time at a pressure of 60 lbs. In putting them in, it was thought that the saving they would effect by transmitting more heat would pay for the cost of renewing them in about seven years.

Within the last few years a special form of boiler flue has been adopted by Mr. Arnold of Barnsley, which it is stated with a thickness of plate of $\frac{3}{8}$ inch will stand a pressure of 500 lbs. without collapsing. The successive rings of plates forming the flue, instead of being truly cylindrical as usual, are rolled barrel-shape or slightly concave towards the longitudinal centre line of the flue, and are united by flanged joints; the bulged shape of the plates and the flanged joints together enable expansion rings to be dispensed with. Inside the flue is fixed a long water-tube, about half the diameter of the flue, sloping upwards at a slight inclination from the back end of the flue, where it communicates with the water space beneath the flue, to the front end immediately behind the fire-grate, where it communicates with the water space above the flue. It tapers slightly in length, being larger in diameter at the front end than at the back end, so as to facilitate the escape of the steam generated from the water passing upwards through the tube from back to front. Boilers with these flues and water-tubes have been adopted at the Denaby Main Colliery, near Doncaster.

Another mode of boiler setting may here be referred to, which, although it is not in use at collieries at present, appears to be of interest from the fact that in one respect it is a return to an old principle. It consists in the adoption of the old wheel flue, and has been brought out by Mr. Livet, who claims for it complete combustion of fuel, with a minimum quantity of smoke, and a low temperature of the gases escaping to the chimney.

Although the principle is not new, there are some special features in the plan which deserve notice. The gases are made to travel only twice the length of the external shell of the boiler; and at both ends of the boiler the flue is enlarged to form chambers, so as to reduce the speed of the gases for the purpose of obtaining complete combustion. The shape of the flues gives free access for inspecting the boiler, which is supported upon cast-iron saddles, thus preventing the brickwork from touching the boiler. The ample area and shorter length of the flues allow of a shorter chimney than is usual with ordinary modes of setting boilers; the height found by present practice to be most suitable is between 40 and 70 feet.

Gas Producer.—The Wilson gas producer is well known, but its application for the purpose of firing boilers has not been adopted on a large scale. At the Alfreton Collieries this mode of firing boilers was adopted in order to provide against making smoke. The coal is filled into the hopper H, Figs. 8 and 9, Plate 123, where it is kept from entering into the producer by the bell B. When a portion of the volatile matter has been emitted in the shape of smoke from the coal in the hopper, the bell is lowered, and the coal dropped into the producer. The steam for the jet is supplied from the boilers through a 1-inch steam pipe S, from which it is delivered into the tuyere T through the jet J. The object of the jet is to take in with the steam a certain proportion of air. The gases pass off through the flue F, which can be regulated by the valve D. There is another valve V, situated close to the boilers, which acts as a stop or regulator valve. The water stands in the bottom trough at the level shown. Holes R are provided for the purpose of stirring up the cinder, and for poking it into the water trough. This "water-bottom" producer makes more gas than the ordinary producers, to the extent of about 25 per cent. So far as the particulars kept extend, the total cost of repairs to the ordinary producers will run to about £20 a year, and to the water-bottom producers from £10 to £12 a year. The brickwork stands much better in the latter. The three producers used at the Alfreton Collieries require the following labour:—

		s.	d.	s.	d.
Day shift.	1 superintendent who attends to feeding . .	4	10		
	1 man wheeling away cinders &c., ½ day at 3/6 .	1	9		
	1 fireman in charge of boilers	4	3		
				10	10
Night shift.	1 superintendent at producers, cleaning &c. . .	4	10		
	1 man cleaning	3	6		
	1 man in charge of boilers	4	3		
				12	7
Total cost for every 24 hours				23	5
The cost of stokers in the ordinary way would be, say					
	2 men at 4/3	8	6		
	2 men at 3/6	7	0		
				15	6

In economy of fuel, it is found that there is a difference of about 15 per cent. in favour of careful hand-firing, as compared with firing by gas by this process.

Steam economiser.—A simple form of steam economiser, which is not generally known, is the Gosling economiser, consisting of a succession of three or more metal discs, placed transversely and centrally, one behind another at some distance apart, within the flue-tubes of Lancashire boilers; the discs are of smaller diameter than the flues, leaving a narrow annular space all round, through which the hot furnace gases are thus compelled to pass in close contact with the flue surface. The application is inexpensive, not amounting to more than about £15 per boiler. The saving effected is most marked where no cross tubes are used. The discs can be placed within the boiler flues in about an hour by an ordinary fireman. The engineer at the Beckton Gas Works reports the saving effected by these economisers, as proved by a number of tests, to be equal to 20 per cent.

5. Haulage of Coal.

The subject of underground haulage is much too large and important to be dealt with here, except in the briefest manner; but some of the special systems and appliances which have been developed in recent years may be referred to.

Steel Sleepers.—The ordinary life of a wooden sleeper used underground varies very much with the temperature and the degree of moisture which exist in a pit; but as a rule the ordinary sleepers will last only for a few years; and for the usual gauge of tramroad the cost of the hard wood sleepers is about fourpence each. The writer has adopted steel sleepers on a large scale, and the main roads of the Nunnery Colliery are laid with these throughout, of the form shown in Figs. 16 and 17, Plate 124; in Fig. 18 is shown the attachment of the rail to the sleeper. These sleepers cost 1*s.* 3*d.* each, and in their duration and the saving in labour they have fully repaid the extra outlay. Another form of steel sleeper is shown in Figs. 19 and 20.

The Endless-Rope system of haulage has been largely adopted during recent years; but very little development of the endless-chain system has taken place, the reason probably being that it is more difficult to apply efficient driving power to a chain than to a rope; also the weight to be carried when chain is used is greater, the respective weights of the ordinary endless chain and endless rope being about 18 lbs. and 3 lbs. per yard.

Two principal systems of slow endless-rope are in vogue, namely that in which the rope is carried on the top of the coal tubs, and that in which it is carried below. With regard to the practice of carrying the rope over the tubs, there has been little improvement in the mode of connection which was in use twenty-five years ago, namely a small chain, one end of which is wrapped round the rope a few times, the other end being attached to the draw-bar hook of the tub. Where however the slow-running endless-rope on the ground is in use, a large number of clips or modes of attachment have been brought out; several of these are shown in Figs. 10 to 15, Plate 124, and may be described as follows.

Smallman's Clip, Figs. 10 and 11, Plate 124, is made chiefly of cast or malleable iron. It is working very heavy gradients satisfactorily, and is easily detached from the rope.

Fisher's Clip is made of wrought-iron, with a malleable bush to clasp the rope, as shown in Fig. 13, Plate 124. The hinge is at

the bottom, below the rope; and the clip can easily be attached to the rope, and secured by the sliding cap or hoop. The bushes are made of soft metal, and are easily replaced when worn. A boy is required both to attach and to detach this clip. It is taking 7-cwt. tubs down an endless-rope self-acting incline, with a gradient of about 1 in $3\frac{1}{2}$ in the steepest part; and the present rope has been at work over six years.

Woodthorpe Clip, Fig. 14, Plate 124, is made entirely of wrought-iron, and is constructed on the same lines as the Fisher clip; but the hinge is here above the rope, which gives it a pincer action. The advantage of this clip over the Fisher clip consists in the means provided for adjusting its gripping power, by lowering the hoop or cap as the rope wears the clip away; this enables the Woodthorpe clip to be worked without bushes.

Hanson's Clip requires a boy to attend to it when in use, and is available for hauling heavy trains up to 20 tons. It grips the rope by a wedge action, and is attached and detached by means of a short lever. It has worked for many years at the Nunnery Collieries very satisfactorily, both on heavy gradients and round curves.

Nunnery Screw Clip, Fig. 12, Plate 124, has been at work for some years in the Nunnery Parkgate seam. It is made of wrought-iron, and the weakest part is the loop, which is constructed so as to give way when the tub gets off the tramway. The jaw which grips the rope is about 5 inches in length, and is tightened by a screw. It is hauling ten tubs, and is capable of working on steep gradients and round curves.

Cannock Chase Clip also grips the rope gradually by a jaw tightened by the slow action of a screw, and thus avoids a sudden strain on the rope. A hinged link from the jaw to the drawbar of the tub allows the clip to adjust itself to the flexibility of the rope.

Nunnery Detaching Clip, Fig. 15, Plate 124, was designed with the view of having the tubs automatically detached from the rope, which is gripped by two jaws, jointed at the point where the clip is attached to the drawbar of the tub. An arm stands out on each side

from the cap or hoop. These arms strike against a sloping surface at the point of detachment, and by raising the cap set the tub at liberty; the raising of the cap forces the jaws apart, and liberates the rope. This clip has worked very well with single 10-cwt. tubs upon a gradient of about one in four. It can work however only upon a straight road.

Tail-Rope system.—One or two points may here be mentioned which indicate some improvements within the last few years. It has usually been the practice to have all tail-rope engines working with spur gear, with the object not only of multiplying power, but also of getting a gradual start in running the haulage. The adoption however of direct-acting engines has proved quite successful; and this plan is now working at the Nunnery Colliery, where the speed of the train reaches about 15 miles an hour. Another improvement in the design of haulage engines is the adoption of a friction clutch in place of the old-fashioned dog-tooth clutch, which was liable to breakage and difficult to put into gear. The friction clutch can be easily put in and out of gear whilst the engine is in motion.

In tail-rope haulage the wear of the sheaves used for conducting the ropes is often serious, but takes place only in the trod of the wheel; the whole wheel has therefore to be renewed, whilst the rest of it is practically unworn. This point has been successfully dealt with by the adoption of a false trod of cast-iron or steel in the larger class of wheels; and a section of this, as now used in some Yorkshire collieries, is shown in Fig. 21, Plate 125.

An important point in dealing with underground haulage is the lubrication of the axles of coal tubs; and some years ago the chief new processes in vogue were described by the writer in the Transactions of the North of England Institute of Mining Engineers (1876, vol. xxv, page 215). Since then a process has been devised by Mr. Elliott, which has been adopted at a number of collieries, and may be referred to as a successful invention. In the ordinary mode of oiling by hand, time is lost in the screening of coal, as the banksman who tips the tub loses time whilst the

axles are oiled; and both in the ordinary process of greasing, and in the use of india-rubber or cogged wheels, a good deal of oil is wasted, and thrown about the tubs and the screen bank. In Elliott's lubricator, shown in Fig. 4, Plate 121, a cap of sheet steel encloses each axle bearing; and a layer of felt within it absorbs sufficient oil at one lubrication to last from one to three months if the roads are dry. The axles are less worn in dusty or wet roads, because the covers to some extent prevent the oil from being washed off, and prevent dirt from getting to the bearings. The adaptation of this lubricator to haulage sheaves and rollers is also carried out. When the first tests were made with this lubricator, it was tried by running a single bearing in a dusty chamber with just the weight it would bear in ordinary practice; and one application of oil was found to last for a number of revolutions equivalent in distance to a run of 3,000 miles.

Another mode of haulage, which is a combination of the tail-rope and endless-rope systems, has been brought out by an engineer in Cumberland, and is in operation in a colliery under the writer's charge in North Derbyshire. The general arrangement may be described as follows. The rope is endless, and is driven by an ordinary drum, round which it is passed three times. It may be applied to either one or two roads. The tubs are run in trains with a bogey tram at each end, when the road is undulating, these trams being attached to the rope by screw clamps. A number of full and empty trains may travel at the same time, and a speed of ten miles an hour may be attained. The attendant can instantly detach his train from the rope, in case of an accident. This plan saves one-third in the length of rope, and it is found to answer well in working round curves. The life of the ropes compares favourably with that of haulage ropes used in other systems.

Steep Haulage.—An interesting mode of hauling coal in the case of steep seams is illustrated in Fig. 22, Plate 125, which represents an incline jig in use at the Silverdale mines in Staffordshire. The seam lies at an inclination of 35° to the horizontal, which is too steep to allow the tubs to run down upon their own road; and therefore a

special carriage is used, upon which the tubs are placed singly. These self-acting jigs are about 200 yards in length, coal being supplied from a number of levels on both sides. A counterbalance tram, which runs down the side of the main carriage road, is lighter than the loaded tub and carriage, but heavier than the empty tub and carriage. The incline man can therefore stop the carriage for coal at the end of any level, which could not easily be done if two carriages were worked side by side. This system enables a narrower road to be used than would otherwise be necessary.

Haulage by Electricity is at present in its infancy, but has already been successfully applied in Yorkshire. An electric motor has recently been designed by Messrs. Walker and Immisch, for dealing with roads of various inclinations. This machine is intended to provide mechanical haulage in remote parts of extensive mines, where the introduction of rope haulage would be both costly and uneconomical. The advantages which electricity offers as a cheap system of transmission with high efficiency render it the most convenient power, where it can be used with safety, as can be done on the main haulage roads in most mines. In ordinary rope haulage a large portion of the engine power is absorbed by friction, to which the wear and tear of ropes is principally due. By making the rope stationary, the power required to move the rope, and the wear and tear caused by the friction, are both avoided. The electric motor is mounted on a wooden carriage, and derives a supply of electricity from an overhead conductor by means of a traveller, and actuates through gearing a clip pulley, say 2 feet diameter on trod, on which the stationary rope rests. On the clip pulley being driven in one direction or the other, the locomotive will move forwards or backwards, and the power of the motor will be applied to drawing the load. As the driver will be with the load, there is no need of signalling to a distant point. The advantages claimed for the plan are the following:—(1) the saving of all the power required in ordinary haulage to keep the rope in motion, which in consequence of the friction is a considerable part of the total work done; (2) a saving in the life of the rope, in consequence of the abolition of

such friction; (3) a rope made from cheaper wire can be used; and (4) all lubrication of rollers and pulleys is dispensed with.

6. Coal Getting.

Coal-cutting Machines.—Very little progress has been made during the last twenty years in the replacement of manual labour by machinery for the getting or hewing of coal. It was thought at first that such machinery would be economical only in the case of coal seams which were both hard and thin; but experience has shown that the only two conditions which are essential to success are a fairly strong coal and a good roof. Without going into details as to the merits of various plans, it may be sufficient to mention that at a colliery in South Yorkshire, with which the writer is connected, about 700 tons of coal per day are cut by a rotary machine, the design of which has been arrived at as the result of many years' experience. It consists of a horizontal wheel, armed with cutters fixed round its circumference, and driven through gearing by a pair of horizontal cylinders working right-angled cranks on a horizontal shaft; the whole is mounted on a carriage travelling along rails. The first cost of a coal-cutting plant, including air-compressor, pipes, and coal-cutting machine to cut about 300 tons per day, is about £3,500. There is a distinct saving of labour in the use of the machine, but this has not as yet been of much advantage to the coal owner; the chief advantages are that a larger quantity of round coal is produced, and the most arduous and therefore the most expensive part of a collier's work is done by machinery. Coal-cutting machines driven by electric motors are not uncommon in America, but have only recently been adopted in England. One is at work at a colliery near Leeds. A comparison of this system with the machine driven by compressed air does not as yet appear to show any advantage.

Drills.—The employment of machinery to deal with the more arduous portion of the miner's work becomes yearly of more importance; and whilst the undercutting of the coal can now be

done extensively by mechanical means, so the drilling of holes in coal and stone, which was formerly done entirely by hand, by means of percussion drills, is now performed by mechanical drills. With an effective machine for drilling holes for blasting, of which the ordinary cost is 18*s*. and the weight 60 lbs., one man will drill a hole in coal to a depth of three feet in a minute and a half, as compared with fifteen minutes required for drilling a similar hole by hand by the old method. For drilling holes in stone, a machine is now largely used, of which the cost is about £6 and the weight about 1½ cwt. This machine will drill a hole in hard stone in twelve minutes to a depth of three feet, the time taken by manual labour with the ordinary drill being thirty-five minutes.

With regard to the tools used by the miners themselves, it is of course of special importance to have these of the best possible construction. Interchangeable picks are now largely used, some having the wooden haft capped with a steel socket or bridle, through which the pick head is inserted and locked securely by a steel wedge, whilst others made with an eye-hole in the head slide upon the pick shaft and can be rigidly fixed thereto.

A coal heading machine, which has already been applied on an extensive scale, has been brought out by Mr. Stanley of Nuneaton. It cuts an annular groove about 5 feet diameter in the face of the heading, leaving a core which either falls or is broken off as the work proceeds. The coal and slack are passed back behind the machine, and loaded into tubs, ample room being left for the passage of men and material on one side, without moving the machine back. It travels on two broad central tandem wheels, working on the floor of the heading; and during the process of cutting is fixed by screw-jacks to the top and sides. The frame of the machine carries a longitudinal central screwed shaft, which is made to advance, while the frame, carrying the engine that drives the shaft, remains fixed in the heading. On the front end of the screwed shaft is mounted a pair of opposite arms, each carrying at its extremity a long face-cutter projecting forwards horizontally. By their revolution an annular groove is thus cut, until it has reached the required depth, when the driving wheel is thrown out of gear, and the jacks are slacked; and

after the cut coal has been removed, the frame by other gearing is run forward along the central screwed shaft, ready to be set for another cutting. The speed at which the heading can be driven varies according to the nature of the seam and surroundings in which the machine is put to work. In favourable coal a distance of a yard an hour can be averaged for some time; but it is hard work for the men to follow it up for any length of time, on account of the large quantity of stuff to be handled. In the Nuneaton Colliery a distance of 64½ feet has been done in 24 hours in a dip heading inclining about 1 in 5, and the difficulty of loading in the heading such a quantity of material as this yielded was the main hindrance; on the level the tubs could have been dealt with more easily. A machine was lately sent to Colorado in the United States of America, on condition that it should cut in the first instance at the rate of 2 feet an hour for 24 hours in three shifts. The seam in which it was tried was unfavourable, because the core had to be all wedged off, being free from joints or partings. The terms of contract however were fulfilled.

Steel Girders.—During the last eight years there has been a great development of the use of steel girders and props underground, in place of wooden beams and props; and at the Nunnery Colliery there are now in the pit girders to the value of about £5,000. It was found that the dampness of the pit caused the timber to rot, or to become unsafe in about two years. The advantages of steel over timber are:—(1) extra durability, and thus reduction in the cost of repairs. (2) The girders can be used again and again; because when they are bent, as is frequently the case, they are sent to the steel works and straightened. (3) They are light and handy; the weight of a 10-foot steel girder as used at the Nunnery Colliery is 166 lbs., whilst a beam of Norway timber of similar strength weighs about 300 lbs. (4) The small space they occupy allows extra area for ventilation, the increased area being from 5 per cent. to 10 per cent. of the total airway. In Figs. 30 to 33, Plate 127, are shown steel girders in use at the Nunnery Colliery; and Figs. 24 and 25, Plate 126, show props and beams of drawn steel, as made by Messrs. Howell and Co. of Sheffield.

7. Ventilation of Mines.

The elements of danger, waste, and inconvenience in furnace ventilation for mines have caused an almost general adoption of mechanical ventilators; and many endeavours have been made to improve the ventilating fans which were in existence twenty years ago.

Fans.—The considerations to be aimed at in selecting a mechanical ventilator are as follows:—first cost of fan, engine, and foundation; future cost of maintenance; economy of fuel and stores; useful effect of fan. Several committees of mining engineers have been formed to report upon the relative merits of various machines; and as at the present time a series of exhaustive experiments are being made by a Committee of the Northern Institute of Engineers, it may be sufficient if in this paper the writer simply mentions some of the chief types of ventilating fans in operation in this country. These fans are:—the Guibal fan, Walker's improved Guibal fan, Cockson's, Schiele's, Capell's, Waddell's, and Lupton's fans.

The Guibal fan is that most largely adopted, and is so well known that it needs no description. In Walker's improved Guibal fan the chief variation in the style is the increased strength, designed with the view of obtaining the same results with a smaller diameter of fan; and the air, instead of being admitted as in the Guibal fan on one side only, is admitted on both sides. The Guibal movable shutter is replaced by an anti-vibrating shutter, which is very effective in its action.

The tendency recently has been to adopt fast-running fans, which however are most suitable where limited quantities of air are required. Four years ago the writer adopted this principle at the Woodthorpe Colliery, near Sheffield, by applying an 8-foot Cockson fan, driven direct without gear by one of Willans and Robinson's direct-acting engines, which runs very quietly at a speed of 280 revolutions per minute. At this speed the fan gives about 58,000 cubic feet of air per minute, with 3 inches water-gauge. The engine

since it was started has run about 500 million revolutions, and has cost a very small amount for repairs.

The actual economy in the useful effect of a fan depends upon the cost of fuel; but bearing in mind that the useful effect is found to vary from about 15 per cent. to 70 per cent., the matter is of importance; and in the ordinary carrying on of a colliery the quantity of fuel used in driving a fan engine, which practically never stops working, may be said to be one-fourth of the entire fuel used. The following would be the comparative economical results of various useful effects, in the case of a fan producing a current of 100,000 cubic feet of air per minute with 3 inches water-gauge, assuming that the consumption of coal is 10 lbs. per indicated horse-power per hour, and that the coal used costs 5*s*. per ton:—

Useful Effect. Per cent.	Cost of Coal per annum.	Saving compared with 15 per cent.
15	£462	...
30	£230	£232
40	£172	£290
50	£138	£324
60	£115	£347
70	£99	£363

In connection with ventilating machines, a simple contrivance which the writer is adopting at the Nunnery Colliery may here be mentioned. A new engine-house which is now being completed will be ventilated by taking a pipe from the roof, and passing it into the fan chamber; the air leaving the house will pass up through two ventilators placed in the roof, and thence to the fan.

8. Screening and Cleaning Coal.

Probably more progress has been made in this department of colliery management than in any other during the past few years; partly owing to seams being worked in which there is an increased proportion of impurities to deal with, and partly because the old screening appliances were not effective in separating the slack from the larger coal, and dividing it into different classes. Another difficulty which has had to be overcome is the tendency to break the

coal, both in emptying the tub upon the screen, and in passing the coal from the screen or belt into the coal wagon.

Tipping.—On leaving the cage the first step to be taken with a tub of coal, after it has been weighed, is to get its contents placed upon the screen; and it is obvious that, no matter how efficient a contrivance to do this may be, some breakage must take place. A great improvement is effected by tipping the tub over backwards instead of forwards, so that the coal then falls upon the upper and nearest part of the screen.

In Fig. 26, Plate 126, is shown a still greater improvement, since the upper part of the tippler here forms, as it were, an enclosing lid to the tub. The forward part of the lid opens automatically by sliding back as the tippler revolves, and thus tends to empty the tub gradually. This process is successfully applied at some collieries in the north of England.

In Figs. 27 and 28, Plate 126, is illustrated what is known as the Rigg tippler, which has the advantage of emptying the tub gradually, but retains the disadvantage of losing a considerable portion of the useful screening surface below it, because the tub is still tipped forwards. To this tippler is sometimes applied a door D, which boxes the coal in; and a restraining weight on the door causes it to open gradually when the tub is tipped. This tippler is cumbersome but effective.

The revolving tippler is fixed in three different ways: either lengthways or across the screen, in both of which cases the tub is withdrawn backwards, after being emptied on to the screen; the third method is to allow the tub, after being emptied, to be pushed forwards through the tippler by the succeeding full tub.

In Fig. 29, Plate 126, is illustrated an adaptation of the revolving side-tippler which the writer regards as being most effective both in quickly emptying the tub, in saving breakage, and in passing the coal on to the screen in the best manner. With an ordinary large tub the weight of the side tippler is such that two men are required to turn it over swiftly. In this improved tippler however, the moment the tub is in position, the movement of a handle puts into

gear the wheel W driven by a belt; and steam power being thus applied, the tub is turned right over through an entire revolution, thus returning immediately to its original position. It is then pushed out of the tippler, and passes away to the winding cage. A further improvement consists in the addition of a curved plate P, which is fixed at its lower end R, but yields to pressure at its upper end; it thus breaks the fall of the coal as the tub is tipped, still allowing the coal to reach the screen at the earliest possible moment.

Screening.—Formerly coal was passed over parallel screening bars made of cast-iron; and the open space through which the slack had to pass was to the width of bar in the ratio of about 1 to 2. An improvement consists in using bars made of steel and attached together by rods; and here the ratio of open space to metal varies from 2 to 1, down to 1 to 1, according to the width of the screen. The evil of these fixed screens was that the coal had in many cases to be dragged down to the bottom of the screen by rakes; and whether it went down in this way or by gravity, it was liable to carry with it a considerable portion of small coal.

These difficulties have been overcome by the adoption of jigging screens constructed of steel wire, in which the proportion of open space to solid surface is about 4 to 1. The jigging of the screen consists of a mechanical lateral movement of from 4 to 8 inches horizontally backwards and forwards, which at 80 to 90 revolutions a minute is effective in dividing the large coal from the small. It enables the length of the screen to be shortened, and thus the height of the heapstead formation of the colliery can be reduced by several feet. It is of course desirable in a jigging screen to dispense with surplus weight. The weight of a light steel parallel-bar screen, 12 feet long by 5 feet wide, compared with that of a wire screen of the same dimensions, is 500 lbs. compared with 300 lbs.

Belts.—Following the example of Continental engineers, there has been a considerable development in the use of carrying bands or belts, for the purpose both of sorting coal and of removing impurities. These carrying bands may be said to be confined to two

descriptions: namely the wire belt, which consists of an endless length of woven wire; and the steel-plate belt, which consists of two or three endless chains, carrying steel plates varying in width from 6 inches to 14 inches.

A method of screening has been brought out by Mr. G. C. Greenwell, Jun., whereby the ordinary vibrating screens are done away with, the coal being carried by a travelling belt, which consists of a series of chains, travelling between bars fixed longitudinally, as shown in Figs. 34 to 38, Plate 127. The bars are of different sections, so as to leave narrower or wider spaces between themselves and the chains, as shown in the transverse sections. Thus the slack falls through the first or narrowest spaces at S; then the nuts through the next wider at N; afterwards the cobbles through the widest spaces at C; and the still larger coal is delivered from the shoot at the far end of the belt. The dirt is picked out by hand along the course of the belt, as on an ordinary belt.

An important point in dealing with impurities is the mode of getting rid of the dirt which is picked out of the coal. At the Nunnery Collieries this dirt is conveniently dealt with by dropping it into hoppers running parallel with the belts; from these hoppers it passes into wagons, which carry it away through a subway under the sidings direct to the hoist.

Suitable means of grinding and washing coal have become of greater importance during the past few years, and have been adopted at a number of collieries. One great difficulty in washing coal has been in dealing with the quantity of sludge, or extremely fine coal, which has frequently been thrown away; but a mode of collecting it for use has now been adopted in Scotland and also in Wales.

The last point to be referred to in connection with cleaning and screening the coal is the manner in which it can be passed into the wagons with the least amount of breakage. There are four modes of doing this, which are more or less effective:—either firstly, by lowering and raising the outer end of the delivery shoot, thereby increasing and diminishing the steepness of its slope; or secondly, by a subsidiary shoot, hinged on the outer end of the fixed shoot and held up by a counterpoise, which gives way gradually under the

weight of the coal delivered upon it; or thirdly, by adding a telescopic sliding prolongation to a fixed shoot, so as to lengthen it or shorten it without altering its slope, the outer end of the telescopic slide being at a lower or higher level according as it is protruded to a greater or less extent; or fourthly, by delivering the coal from the shoot into a bucket or scoop, which when full descends slowly under the restraint of a counterpoise, and automatically empties itself on touching the floor of the wagon or the surface of the coal already deposited thereon. The object in every case is to reduce to a minimum the height of free fall through which the coal has to drop. The peculiar manner in which the joints in the belt render it difficult to prevent the breakage of coal has been dealt with at the Nunnery Collieries by the adoption of a double plate.

The writer feels that he has been able to refer only in a brief and superficial manner to the wide range of subjects embraced in this paper. Many of the appliances here alluded to are worthy of special papers which would describe them more fully. The reference here made however to the numerous mechanical appliances, upon which the mining engineer has to rely in order to promote economy in the Working of Collieries, will serve to indicate how closely the sciences of mining and mechanical engineering are allied.

Discussion.

Professor Arnold Lupton considered the paper just read was most interesting and valuable; and the author was thoroughly qualified to speak about improvements in mining during the last thirty years from his own experience over the whole of that period. No doubt the improvements which had been introduced had resulted in nearly trebling the production of coal, and had been such as to engage the attention of engineers of all classes.

Mention had been made in page 361 of the method of sinking through quicksand by means of freezing. That method was especially applicable where quicksand was met with at a considerable depth below the surface. Where it was at the surface, it could be dealt with by piling, or by the pneumatic method; but where it was met with at a great depth, the shaft could not be widened out to the requisite diameter for applying the ordinary method of piling, and the pneumatic plan was out of the question, owing to the great pressure involved. By the pneumatic process he had himself sunk a pit through quicksand to a depth of about 100 feet under a pressure of four atmospheres, which was about as great as it was convenient for the men to work in. In a diving dress a man could work at a much greater depth than in a diving bell; but a little over 100 feet depth was as far as it was advisable for the men to work in; at that depth they got along fairly well. The pneumatic process was exceedingly simple, and was well known to all bridge-builders, who constantly sunk foundations by that means. But there was a difference between sinking a shaft and a bridge foundation. For the latter it was necessary to sink a hole, which had then only to be filled up with concrete. But in sinking a shaft, not only had a circular hole to be carried down into the ground, but then the difficulty was to make a watertight joint between the cylindrical tubbing and the solid strata at the bottom, without filling up the shaft with concrete.

The speed of winding at Ynysybwl Colliery (page 369), from a depth of 500 yards in 35 seconds, representing an average of 30 miles an hour, would involve a maximum speed approaching

(Professor Arnold Lupton.)

60 miles an hour in the shaft, which it would be admitted was a considerable speed, rendering it necessary that all the machinery and appliances should be in perfectly good order. It should be borne in mind that throughout this country about 500,000 men or more went down a pit every morning, and came up every night, and it rarely happened that any of them met with a fatal accident in the shafts of any of the mines. That fact spoke volumes for the care taken by the rope-makers, engine-builders, and engine-drivers.

As to economy of fuel in winding engines, he considered it was not requisite in colliery engineering to adopt the refinements which elsewhere were found advantageous. It was only necessary to make the valves and ports large enough, in order to secure a great improvement. Twenty years ago he had made an enquiry into the winding engines throughout the country, and he then found that fully one-third of the power of the steam was wasted through not having the ports and valves of sufficient area, particularly the exhaust port. In this respect the engines had not been much altered since that time; and although the ports and valves might have been ample enough for a slow-moving engine, they were not so for a winding engine going at 700 or 800 feet per minute. Had James Watt had the designing of these engines, he was quite sure he would have made the ports and valves large enough, so as not to take one-third of the steam power in the engine simply to drive the exhaust steam out of the cylinder.

The feature of the ventilating fan designed by himself (page 387) was the utilisation of the skin-friction of the fan, instead of having it altogether wasted. As the fan revolved and the air from the mine entered into it, there was of course a great deal of surface friction between the fan itself and the air outside; this friction was utilised for the ejection of the air from the casing, with the result of effecting a considerable economy in the working of the fan.

In reference to the use of electricity for transmitting power in mines (page 383), he could not quite agree that it was *the most* convenient power, though he did quite agree that it was *a* convenient power. No doubt those who had used it in Yorkshire for underground pumping and haulage had found it both convenient and satisfactory.

Mr. Bainbridge said that the paper had dealt with a large number of items in colliery engineering, every one of which was meant to effect some saving in labour, fuel, or repairs. There were between 3,000 and 4,000 collieries in this country, and 75 per cent. of the appliances described in the paper were not yet employed at all in more than half a dozen collieries. The paper was of course addressed especially to those mechanical engineers who were interested in coal mines; and he had endeavoured to draw their attention to the matters which from his own experience he was led to think chiefly required consideration at the present time in colliery engineering.

He expressed his gratitude to Professor Hicks, the principal of Firth College, for his kindness in providing for showing so well by lime-light the drawings illustrating the paper; and he congratulated him upon the success of the arrangements he had so obligingly made for darkening the room and lightening it again in so short a time as only about a minute and a half.

The President had great pleasure in inviting the Members to join him in a cordial vote of thanks to Mr. Bainbridge for his acceptable paper. Dealing as the author did with collieries mainly in the Sheffield district, he had none the less contributed an amount of information and experience which could not fail to prove of practical value to mechanical engineers concerned with coal mines in all the other districts also throughout the country.

DESCRIPTION OF THE PARK GATE IRON AND STEEL WORKS.

By Mr. CHARLES J. STODDART, Managing Director.

These Works are situated about 1½ miles from Rotherham, and are among the oldest and most extensive works in the midland counties. They were commenced on a small scale in 1823, by two gentlemen from Sheffield; and after passing through the hands of several owners were known as the Birmingham Tin-Plate Works. Subsequently they came into the possession of Messrs. Samuel Beale and Co., from whom they were purchased in 1864 by the present owners, the Park Gate Iron and Steel Co.

Old Iron Works.—The oldest portion of the works is situated on the west side of the turnpike road from Rotherham to Swinton. The staple industry in the early days of Messrs. Beale was the manufacture of iron rails for the leading railways in this country and abroad. A quantity of these rails laid on the Metropolitan Railway were case-hardened, that mode of treatment being then considered the best for increasing their durability, before the introduction of the Bessemer process. Since then, the use of iron rails has practically ceased, and the works have been adapted for other purposes.

At the old blast-furnace on this western side of the works the original trials were made of ironstone from the present field of Lincolnshire iron ore at Frodingham, the consumption of which has increased so enormously during the past few years. On the same side of the works also were rolled the majority of the plates for the Great Eastern steamship.

Plate Mill.—A demand for larger plates having arisen, Messrs. Beale erected the present plate-rolling mills on the east side of the road; and by means of the reversing clutch they were enabled to

roll the very large stern plates required for the Great Eastern ship. About 1856 a demand arose for rolled armour-plates, as the hammered ones were not found to be very satisfactory. From the experience gained in rolling the large plates for the Great Eastern, the work was undertaken, and for nearly five years the sole manufacture of rolled armour-plates was carried on at these works. In those days armour-plates were only from $4\frac{1}{2}$ to 5 inches thick, and were supplied for a large number of the ironclads built during that period.

The present planing and fitting shop was erected at the same time, in order to plane and slot these plates to the finished dimensions. Amongst other extensive alterations and additions two new blast-furnaces and bar mills have been erected by the present company.

Present Iron Works.—The iron works now consist of 5 blast-furnaces, including 2 at The Holmes; 4 plate and sheet mills; 3 bar mills; 80 puddling and ball furnaces; 180 coke ovens; 5 steam hammers; 25 pairs of shears; and other necessary appliances. They are capable of turning out per week 1,400 tons of pig iron, 850 tons of iron and steel plates and sheets, 450 tons of iron and steel bars, and 500 tons of coke made from Barnsley Hards. About 1,000 tons of ore per day are raised from the company's ironstone mines in Lincolnshire and Northamptonshire. The consumption of coal is about 1,000 tons per day; and the coal is obtained from the Barnsley seam, the works being connected by rail with a large number of collieries in the vicinity. The steam required for the 78 engines of all kinds is generated by 85 boilers, and is nearly all raised by utilizing the waste heat from the furnaces. There are also the necessary foundries, pattern, wagon, blacksmith and boiler shops, gas works, stables, &c.

New Steel Works.—In 1887 it was considered advisable to supplement the iron manufactures by the addition of the manufacture of steel. Operations were commenced on 1st January 1888, and the first cast of steel was made on 26th October 1888. The steel works have been designed and laid out so as to economise labour as much as

possible, and to prevent the necessity of taking the steel backwards and forwards. The gas is produced by twelve 8-cwt. Wilson gas producers, from which it is led through culverts to the range of boilers, and also to the four 25-ton Siemens-Martin steel furnaces; two of these are for the manufacture of steel by the acid process, and two by the basic. From the casting pit the ingots are lifted by steam travelling cranes and landed upon bogies on the mill floor, where they are weighed and charged hot into the reheating furnaces; they are then rolled into slabs or billets as may be required.

Cogging Mill.—The cogging mill is driven by a pair of 50-inch reversing engines, coupled up to a pair of 45-inch cast-iron pinions, which have straight teeth, 38 inches long and 9 inches pitch. The train can be driven at a speed of 60 revolutions per minute. It consists of one pair of 36-inch slab rolls 7 feet long, and one pair of 36-inch cogging rolls 9 feet long. Both the top rolls are balanced by hydraulic power, and so arranged that the slab rolls will rise 30 inches, thus enabling slabs to be edged and finished up to 36 inches wide. The cogging rolls will take ingots 18 ins. × 14 ins., and finish any size down to $1\frac{1}{2}$-inch square billets or 6 ins. × 2 ins. slabs; they are designed to roll the various sizes required in the works and for general trade. In this mill, without changing rolls, any size of slab can be rolled and sheared, from 36 inches wide and 10 inches thick to 6 ins. × 2 ins.; and billets from 10 inches to $1\frac{1}{2}$ inch square.

The slab rolls are fed by 50 feet of live rollers, and the large ingots are turned on edge by an apparatus designed by Messrs. Davy Brothers of Sheffield. The finished slabs are then taken by another series of rollers to the large bloom shears, which will cut any size up to 36 inches wide and 10 inches thick. When the slab has been cut, it is lifted by a hydraulic crane and weighed on the weighing machine; after which the crane stacks the slabs up, or loads them into railway wagons.

The billet mill is fed by 52 feet of roller gear, and the billets when finished are taken by live rollers, 160 feet in length, to the smaller shears, which will cut up to 8 inches square. A saw and

benches have also been erected in this mill, so that it could be made available for rolling any large sections of girders or channels, or even rails if required.

Plate Mill.—This mill was specially designed to meet the increasing requirements for large plates for marine and other boilers, and is perhaps the most powerful and novel mill in the country at the present time. It is driven by a pair of horizontal reversing engines with cylinders 50 inches diameter and 5 feet stroke, which run at a speed of 80 revolutions per minute and are geared so as to run the mill at a speed of 36. The engines are coupled to a pair of pinions of the same size as those in the cogging mill.

The train consists of one pair of breaking-down rolls 36 inches diameter and 7 feet long; one pair of finishing rolls 36 inches diameter and 12 feet long; and one pair of hard rolls 30 inches diameter and 8 feet long. The 7 feet and 12 feet top rolls are balanced by hydraulic power, the adjusting screws of both mills being worked by small engines with 7-inch cylinders and 10 inches stroke.

All the three pairs of rolls in this mill are fed by live rollers, so that the largest plate can be worked with ease and economy. The slabs used in this mill are brought by the live rollers from the slab mill, and lifted upon bogies by hydraulic crane, and charged direct into the furnace, so that a large proportion of the finished material is never allowed to get cold from the ingot until the plate is finished. The plates when rolled are examined, and taken by a 10-ton overhead traveller to the large shears; and when finished are taken by the same crane to the weighing machine, and finally loaded by the crane into railway wagons.

The large plate shears have 10 feet blades with 30 inches gap, and are arranged to cut plates up to $1\frac{3}{4}$ inches thick and to split 7 feet wide. Plates can be rolled in this mill up to 11 ft. 6 ins. wide or 11 ft. 9 ins. diameter, and up to 60 feet in length, according to width and thickness. The large rolling-mill engines, the shears, and the greater portion of the mill and roller gear, were supplied by Messrs. Davy Brothers of Sheffield. A piece off each plate is taken

to the test house, which is filled up with shaping, bending, and 50-ton testing machines, supplied by Messrs. J. Buckton and Co. of Leeds.

The hydraulic power for the whole of the steel works is worked at a pressure of 700 lbs. per square inch, and is supplied by a pair of 20-inch horizontal engines, made by Messrs. Henry Berry and Co. of Leeds. An additional pair with 26-inch cylinders is in course of being supplied by Messrs. Markham and Co. of Chesterfield. The steam required is supplied by a set of eight Lancashire boilers, 30 feet long by 7 feet diameter, and six boilers erected over the reheating furnaces. At the end of the plate mill is placed a large roll-turning lathe with 33-inch centres and 26 feet bed. This is served by a 35-ton travelling crane, which traverses the whole length of both mills, about 230 feet, so that any one of the rolls can be taken out and put into the lathe with the greatest possible ease. The whole of the steel works are covered by a substantial iron and slate roof, in bays 56 feet wide, 24 feet high at the eaves, and 40 feet in the centre. The total area covered is about 2½ acres.

Steel Production.—The steel works are capable of turning out per week from 700 to 800 tons of steel, and from 400 to 500 tons of plates. The production could be greatly increased by the erection of additional furnaces, as a much larger quantity could be passed through the rolling mills.

Transport.—The necessary material required to carry on the whole of the works is taken over the railways and roads by 7 locomotives, 500 wagons, and 31 horses. The total area of the works at Parkgate is 70 acres, and at The Holmes 30 acres. The works are connected by sidings with both the Midland and the Manchester Sheffield and Lincolnshire Railway, and have also water communication with the ports of Hull, Goole, and Grimsby.

The President considered the paper very interesting as showing the progress of one of the early ironworks in the neighbourhood of Sheffield. It appeared to him however that any discussion was now unnecessary, in view of the author's invitation to the Members to visit the works themselves on the following day. Meanwhile they would like to examine the large number of specimens here exhibited of the work done, which the author had sent for their inspection. He had much pleasure in proposing a vote of thanks to Mr. Stoddart for his paper.

DESCRIPTION OF THE LOOMIS PROCESS OF MAKING GAS FOR FUEL.

[By Mr. R. N. OAKMAN, JUN., of London.

The Loomis process for Generating Gas, which has recently been introduced into the Sheffield district, produces three kinds of gas:—producer or generator gas; water gas for fuel; and carburetted water-gas for lighting. It is with the two former only, and with their application as fuel, that the present paper deals, without entering at large into the general subject of gaseous fuel.

Apparatus.—In Figs. 1 and 2, Plate 128, are shown a plan and elevation of the apparatus employed. It consists of a generator or producer P, of which a vertical section is shown in Fig. 3, Plate 129; a vertical boiler B; an exhauster E and engine; an auxiliary boiler; two gas-holders; and suitable steam, water, and gas tubes and pipes, with proper valves and seals. The generator P is cylindrical, constructed of iron or steel, from 7 to 10 feet diameter and 12 to 13 feet high; the lining is of fire-brick, but employed in a different method from that in other water-gas generators. According to the size of the generator and the quality of the fuel, the hearth is either left entirely open to the chamber above, as shown in Fig. 3, or is bridged with fire-brick arches, as shown in Figs. 4 to 7, Plates 130 and 131. The vertical boiler B is usually made 3 feet diameter, and from 17 to 20 feet high; it is of the multitubular type, and is connected at its base with the base of the generator. The exhauster or blower E is preferably of the class known as positive; it is connected with the top of the boiler, and is driven by an engine direct. A suitable washer or scrubber is provided, through which the water-gas passes to one of the gas-holders.

Twofold Operation.—The fuel used in the generators is bituminous coal; the slack is found to work the most satisfactorily. It is

introduced through a feed door D on the top of the generator. Air is also admitted through the same door, and by means of the exhauster is drawn down through the fresh charge of coal, and then through the hot fuel bed beneath. The resultant producer or generator gas is drawn down through a superheater H, Figs. 5 to 7, in the bottom of the generator, up through the vertical boiler to the exhauster, and thence is delivered into a gas-holder for supply to the furnaces. This gas-holder may be small, having to act only as a governor. The heat given off by the gas in passing through the vertical boiler is utilized in producing steam for afterwards making water-gas and for working the engines.

During the time of bringing the fuel to a state of incandescence, the feed door D on the top of the generator is open, thus allowing the attendant to see constantly the condition of the fuel bed. This first half of the operation requires from four to six minutes; after which the exhauster is stopped, the valve V between the boiler and exhauster is closed, as is also the feed door; and steam being introduced through the superheater in the bottom of the generator passes up through the incandescent fuel; the resultant water-gas goes away through a seal S, Fig. 2, to the washer, and thence into another gas-holder. This second half of the operation occupies about the same time as that required for bringing the fuel to incandescence.

The working of the process is exceedingly easy and simple, no skill being required beyond that which a man of ordinary intelligence and without any previous experience in gas-making would acquire in a week's practice. The combustion of coal in the generators is so nearly perfect that there is great freedom from clinker. They have been worked daily for over six months, without requiring the fires to be drawn or to be broken up. The explosions so common in water-gas generators are avoided.

Producer-Gas.—As it is bituminous coal that is introduced into the generator and there coked, the gas thus obtained is of excellent quality; and after having passed down through the hot fuel bed it is free from tar, and may readily be conveyed through pipes to any distance required. Instead of making water-gas in every alternate

stage for the same length of time as producer-gas, the generator may be worked on producer-gas alone, steam being then admitted at various points while the exhauster is running and the operation of making producer-gas is going on. It is therefore not requisite to alternate the action of the generator so frequently as every four to six minutes; but only so much water-gas need be made as may be called for by the requirements of the work to which the process is applied.

From the gas-holder the gas is supplied under pressure into the furnaces, the supply being regulated by the ordinary gas-valve; thus a uniform heat is always maintained. This producer or generator gas is now being used successfully for re-heating, annealing, and hardening metals; for firing tile and pottery, porcelain, gas-retorts, boilers, &c.; and where purity of flame is desirable it is of special advantage, being free from tar and smoke. When the generator is worked so as to obtain the largest amount of water-gas possible per ton of coal, the generator-gas produced in bringing the coal to incandescence is equal for fuel purposes to rather more than half the coal consumed: that is to say, if one ton of coal is consumed in the generator to make 40,000 cubic feet of water-gas, the producer-gas also obtained from that one ton will exceed in value half a ton of coal applied to reheating, &c. The percentage of combustible matter in the producer-gas ranges from 30 to 40 per cent., according to the quality of the coal used.

Water-Gas.—The water-gas made by this process differs from any other water-gas in its peculiar and strong odour, in consequence of which any leaks are readily detected; and it burns with a flame equal to 4 to 10 candle-power, varying with the quality of the coal used and the quantity of gas made per ton of coal. This is due to the hydro-carbons taken up by the water-gas from the bituminous coal. The calorific power of the gas is thus increased; and in the experience of those who have used water-gas made from anthracite coal, from coke, and also from bituminous coal, the gas made from the latter has been found the most suitable for the treatment of steel, having a higher calorific power than water-gas made from either anthracite coal or coke. As an indication of its merits for heating

steel, it has been proved to furnish the best heat for treating watch-springs, giving a better quality of springs than can be obtained by the use of any other fuel. It has been in use a year or more for this and other purposes at the American Waltham Watch Works in the United States; and for a longer period in heating fine steels for forging, hardening, and tempering, in cutlery and similar work.

The quantity of water-gas produced per ton of coal consumed in the generator ranges from 35,000 to 45,000 cubic feet, some coal yielding more water-gas than others. In respect of stability, the gas is well fixed; there is no condensation.

The following are analyses of the two gases taken from the gas-holders:—

	Water-Gas.	Producer-Gas.
Carbonic Acid . .	4·5 per cent. ..	7·4 per cent.
Carbonic Oxide . .	36·6 „ ..	22·5 „
Hydrogen . . .	57·4 „ ..	13·2 „
Nitrogen . . .	1·5 „ ..	56·9 „

Joint Production of both Gases.—While the process recommends itself for making water-gas, the use of this gas alone as a fuel for all purposes is not advocated. It is in the production and application of the two gases jointly—producer-gas and water-gas—that the greatest economy appears to lie; and it is therefore according to this combined method that the development of the plan has taken place. First of all the raw coal becoming coked in the generator is raised to a state of incandescence, and the gas thus produced is employed where lower heats are required, as in re-heating, annealing, boiler firing, &c. Afterwards the incandescent coke is used to produce water-gas, for employment where higher heats are wanted, as for melting metals, and for heating metals in small forges or furnaces where regenerating is not practicable, and for any purpose where high heat on light work is desired. The fuel economy differs much with the work and with the conditions under which it is done.

Economy of Water-Gas.—Two examples may be given, which are probably the extremes in the application of water-gas, and are the

results of practical working. In heating steel in small forges for making files, cutlery, and similar work, the fuel saving over coal or coke firing has been found to exceed one-third. On the other hand, in melting steel in crucibles the economy in fuel is fully 75 per cent. as compared with coke firing. Beyond the saving in fuel it will be understood that there are also other large economies, to which reference need not be made here.

Many leading works in the United States are using the process; and in the Sheffield district it has been for several months in practical operation in the works of Messrs. Thomas Firth and Sons, and is now being introduced into those of Messrs. Howell and Co., and Messrs. Newton Chambers and Co.

Discussion.

Professor J. O. ARNOLD, referring to the statement in page 403 that "the combustion of coal in the generators is so nearly perfect that there is great freedom from clinker," pointed out that the clinker arose from the fusion of the ash of the coal, which was composed of iron as the base and silica as the acid. It could hardly be supposed the meaning was that the combustion of coal in the generators was so perfect as to burn the ash; yet otherwise the meaning intended did not seem clear.

As to what was the calorific intensity of the gases obtained in this process, no statement was furnished in the paper. A question which especially interested Sheffield manufacturers was whether water-gas had ever been applied to the production of steel in the open-hearth furnace. Although it was stated in page 404 that the water-gas made from bituminous coal had a higher calorific power than water-gas made from either anthracite coal or coke, owing to the hydro-carbons which it took up from the bituminous coal, yet no information was given as to the actual calorific power, or, what was more important, the calorific intensity of the gas.

It was further stated in page 404 with regard to water-gas that, "as an indication of its merits for heating steel, it has been proved to furnish the best heat for treating watch-springs, giving a better quality of springs than can be obtained by the use of any other fuel." The question naturally suggested itself, why was that so? was its action chemical or physical? was there a sort of carburization of the watch-springs? or was it meant that no other mode of heating would give so equable a heat? An explanation upon this point would greatly interest the makers of spring-steel in Sheffield.

Another remarkable point was the statement in page 404 that water-gas made by this process had a peculiar and strong odour, whereby any leaks were readily detected. But in the analysis given in page 405 the only items included were carbonic acid, carbonic oxide, hydrogen, and nitrogen, none of which had any strong smell. There must therefore be some omission in the analysis, because the smell, which was a very valuable property for the water-gas to possess, must be due to the hydro-carbons which were not included in the analysis. These latter seemed to him to constitute rather an important omission. Without a full analysis of the gas it was impossible to calculate theoretically its calorific intensity.

A critical point, which could not fail to interest Sheffield steel-makers, was approached in page 406, where it was stated that "in melting steel in crucibles the economy in fuel is fully 75 per cent. as compared with coke firing." This was so remarkable a statement, that he felt sure there were many in Sheffield who would ardently wish to hear more details respecting it.

Professor ARNOLD LUPTON enquired how the gas furnace worked according to the description given in the paper. It was stated in page 403 that air was admitted through the feed-door on the top of the generator, and was drawn down through the fresh charge of coal, and then through the hot fuel bed beneath. He did not quite understand how the fuel bed beneath got hot. If the air came in at the top, along with the fresh fuel, it would seem natural to expect that the combustion would take place where the air and fuel met, after they had once been set alight. Was there a preliminary process of firing up from below, in order to get the bottom part of the fuel bed hot? and if so, what took place during that preliminary process of getting the bottom part hot? where did the gas pass away, and how was it taken off?

The PRESIDENT would be glad to hear something about the introduction of the process at Messrs. Howell's works, and its operation at Messrs. Firth's, of which mention was made in the paper.

Mr. S. EARNSHAW HOWELL said the apparatus described in the paper was now being put down at his tube works, but it was not yet ready to be got into operation, and he was therefore not in a position at present to say anything on the subject.

Mr. J. ROSSITER HOYLE said, although the process was already in operation at Messrs. Firth's works, he was not yet in a position to furnish any definite data as to the results. With regard to the economy of 75 per cent. however, mentioned by the author, it was distinctly stated in page 406 that the comparison was made with the old-fashioned coke-firing. From what he had himself seen of the working of the process at Messrs. Firth's, there was certainly considerable economy in the use of the water-gas for crucible-steel melting, over the old-fashioned way of heating by coke. As was well known, when melting with coke a natural draught of cold air came from below; and he had no doubt that something like 80 per cent. of

the heat from the coke was lost. The fires were also let out every night and re-lighted in the morning. By the new process of working with water-gas the furnace was kept going day and night without ever letting it cool, and the air required was regenerated before passing into the furnace, thereby effecting a great saving. Messrs. Firth were so far satisfied with their water-gas experiments, that, although they had at present only two generators, they had made arrangements to put down ten or twelve more, should they require them; they naturally wished to have definite data before they went on putting down more plant. Up to the present the experiments had been highly satisfactory, not only with the crucible-steel melting, but also in the Siemens furnace, in which they had tried a few experimental heats. Producer-gas was used for re-heating furnaces, and water-gas for melting.

Mr. Charles Cochrane, Past-President, asked whether regenerators were employed.

Mr. Hoyle replied that regenerators were not used for the water-gas in the crucible furnace, nor in the experiments with the Siemens furnace; in both cases the air only was passed through a regenerator.

The President considered that the saving, whether it were 75 per cent. as stated in the paper or a considerable economy as mentioned by Mr. Hoyle, might be largely due to not letting the heat of the furnace down every night. That seemed to him to be the largest item of loss in the ordinary firing with coke. If the furnace was let down every night in the one case and not in the other, that alone would be sufficient to account for a large proportion of the economy.

Mr. Hoyle added that another source of economy lay in making the gas out of small coal procured at a comparatively low cost, whereas formerly the coke used was purchased at a high price.

The PRESIDENT enquired whether the saving of 75 per cent. mentioned in the paper was in the weight of the fuel, or in its cost; that would make all the difference.

Mr. HOYLE replied that the saving mentioned referred only to the cost of the fuel; and the outlay necessary for the gas-producing plant and for the furnaces was not in this instance taken into consideration.

Mr. GEORGE D. HUGHES asked whether the process was practically applied to the melting of pig-iron, and also of gun-metal and brass.

Professor LUPTON asked what was the temperature of the producer-gas before it entered the boiler in the apparatus.

Mr. OAKMAN replied the temperature was anywhere between 2,000° and 2,500° Fahr.

Mr. JOHN A. F. ASPINALL said he had not yet tried any experiments with water-gas; but it occurred to him that what engineers wanted to ascertain was whether the water-gas was more economical than producer-gas for doing the same work. It had been compared with coke for melting steel in crucibles; and he should like to know whether it was more economical than ordinary producer-gas when the latter was passed through regenerators in an ordinary Siemens furnace. At the present time he was using at the Horwich Works of the Lancashire and Yorkshire Railway producer-gas for melting brass in crucibles, and it did exceedingly well. For some time there had been a little prejudice against it, he believed, the idea being that it did not do so well as the old coke fires. But he had experienced no difficulty with it, and all his small brass castings were now made in a furnace which was heated with producer-gas passed through regenerators in the ordinary way. For large brass castings the brass was melted in a small Siemens open-hearth furnace.

Mr. Charles Cochrane, Past-President, asked what was the duty of the furnace in tons of bituminous coal burnt per day, and what was the cost of the apparatus.

Mr. John Head, in reply to the question as to the efficiency of water-gas as fuel in comparison with producer-gas used in a regenerative gas furnace, said he did not know exactly what gas was made by the Loomis process, but he supposed it was a combination of water-gas and hydro-carbons. If that were the case, it was very little better than ordinary producer-gas. From calculations he had made in regard to pure water-gas, which would be equally applicable to this gas, he had arrived at the conclusion that the difference in the value of water-gas and of producer-gas, both utilized in a regenerative gas furnace, was only $\frac{1}{2}$ per cent.; in other words, if 100 tons of coal converted into ordinary producer-gas were required to do a certain amount of work, $99\frac{1}{2}$ tons would be required to do the same work if the coal were converted into water-gas. That was all the difference, so far as he could make out; and he did not see the need of resorting to the complications necessary for the production of water-gas in order to obtain so slight an advantage. The reason was that in regenerative gas furnaces the regenerators absorbed practically all the waste heat; or if there was any heat escaping, it was only just sufficient to create a draught in the chimney. Another reason for the want of economy in dealing with water-gas was that by its combustion a large proportion of water was formed in the state of steam; and the quantity of heat contained in that steam could not be entirely recovered in the regenerators unless it were condensed into water, which of course could not be done. These were two reasons why water-gas offered no advantage over producer-gas. In one respect however water-gas might give an advantage, namely in greater rapidity of work. Roughly speaking, water-gas would work twice as quickly as producer-gas. But then arose another question, which was, whether there was any material of which furnaces could be constructed to resist the intense heat produced; he was not acquainted with any such material to be obtained commercially.

(Mr. John Head.)

Some steel-melting furnaces heated by radiation had been found to last from eight to twelve months; and some lasted even longer without repairs; but ordinary furnaces were found to last only from four to six months. If twice the amount of work was done in a furnace per day, it did not mean that the furnace would last only half as long, but only about one-eighth as long, or perhaps less.

Sir LOWTHIAN BELL, Bart., Past-President, said that many of the objections which he had urged against water-gas in his own paper on gaseous fuel, read last year in Paris at a meeting of the Iron and Steel Institute (Journal 1889 II, page 139), did not apply to the present paper. At that time there was an opinion broadly put forward, and insisted upon as almost universally applicable wherever heat was required, that the days of solid fuel were past: that no one would any longer think of using solid fuel when he could use water-gas in its stead. As the groundwork of his own objections to any such view, he might say that, unless there was a good and strong reason why fuel should be used in a gaseous state at all, every attempt to employ fuel in that state was attended with an obvious loss. The carbon of the fuel had to be converted into monoxide of carbon, which in point of fact, meant at the outset a sacrifice of something like 30 per cent. of its heating power. But it was quite possible that a condition of things might arise, in which the ulterior benefit far more than compensated for the preliminary sacrifice that had to be made. This was particularly the case with the Siemens regenerative furnace. If ordinary fuel were burnt in an ordinary furnace, there was of course a considerable loss in the heat which escaped into the chimney. By means of gaseous fuel—and gaseous fuel alone, as far as he knew—the heat could be trapped, as it were, on its road to the atmosphere, and brought back again into the furnace. In that way producer-gas was undoubtedly a very valuable commodity, where intense heat was sought for.

With regard to the use of what was called water-gas, which resulted from the decomposition of steam and its resolution into carbon monoxide and hydrogen, he did not say there were not cases in which hydrogen might be very useful; but as to expecting that

the direct use of solid fuel would be supplanted by employing it to decompose steam into hydrogen and oxygen, and to convert a portion of the latter into carbonic oxide, a greater physical delusion had never been entertained. It was impossible to devise any means whatsoever, whereby more heat could be got out of a pound of coal than that pound of coal would afford when burnt directly. Unquestionably hydrogen afforded a heat of great intensity; this was well understood from the fact that when a pound of hydrogen was burnt it produced about four times the heat that could be obtained out of a pound of coal; but then it took four pounds of coal to get that one pound of hydrogen. And when he said four times the quantity, it should be remembered that it was a theoretical change only that took place: that is, although there was as much heat given off from one pound of hydrogen as was equal to that from four pounds of coal, yet the enormous loss had to be encountered that took place from radiation, convection, and many other causes. Hence he considered it would always be wasteful to burn fuel and use part of the heat so obtained in order to obtain hydrogen. In most cases it might well be asked, what was such a high temperature wanted for? In the first place, as Mr. Head had pointed out (page 411), there would be great difficulty in getting any material of moderate price to resist so high a temperature. With ordinary producer-gas in the regenerative furnace there was no difficulty in getting all the heat required; and any heat beyond that, if got at an extra cost, was in point of fact so much money thrown away. He did not hesitate to express his opinion that the substitution of gaseous for solid fuel, as a general rule, was a delusion. But he was not by any means prepared to say that water-gas, for reasons altogether independent of its calorific power, might not be of great value. This was a very different matter from the universal substitution of gaseous for solid fuel. Considering such work as the manufacture of the corrugated boiler-flues made in Leeds, for steam boilers to carry a pressure of 200 lbs. per square inch or even half this amount, it was of course a matter of almost perfect indifference what the cost of the fuel might be. The object was to effect the welding of the two edges of the plates; and if this could be done in a shorter time, or under conditions which admitted of a more

(Sir Lowthian Bell, Bart.)
perfect weld than with ordinary fuel, then of course cost did not enter into the question.

As to any advantage which the so-called water-gas might possess for the treatment of springs for watches at Waltham, he could well imagine that, for heating a delicate piece of steel like a watch-spring, which was required to retain its power of resilience sufficiently to keep a watch going for a hundred years or more, without being impaired in the slightest degree, the hydrogen gas might be a very valuable commodity. Though he could not say that it was so, he was not prepared to deny that it might be. But how much water-gas could the Waltham works use for the treatment of watch-springs? Undoubtedly a very insignificant quantity.

If any one would take the trouble to go through the whole category of uses for which high temperatures were required, he thought the three following conclusions would be arrived at: firstly that, wherever it could be used, solid fuel was the most economical; secondly that, where the conditions of combustion were such that the regenerative system could be employed, the next best thing to solid fuel was producer-gas; and thirdly that the worst of all was to use the heat of a large portion of the solid fuel for the manufacture of hydrogen gas.

Mr. OAKMAN said he had not attempted in the paper to go into the scientific aspect of the subject, but had confined himself to a description of the process, with such results of practical working as might give an opportunity for discussion.

As to the employment of water-gas for the treatment of steel, he had alluded to its use for watch-springs at Waltham, simply to indicate that the water-gas treated the steel more kindly for such small work; and he had found it equally serviceable in his own experience for files and cutlery. Whether its action was chemical or physical, he was not prepared to say; it was true that a more equable heat could be maintained. Previously coal-gas had been used at Waltham; but this not being entirely satisfactory, gaseline had been resorted to, and finally water-gas had been adopted; and he

had been informed that in the physical tests the springs treated with water-gas showed a better and more uniform quality.

As to the odour of the gas, the analysis given in the paper had been made in Philadelphia, without any attempt to determine the olefiant gas. Analyses made in this country showed in two or three cases from 2½ to 5½ per cent. of olefiant gas, which was sufficient to account for the odour. The proportion of olefiant gas would depend somewhat upon the quantity of water-gas made per ton of coal. As much as 49,000 cubic feet of water-gas had been made per ton of soft coal in the United States; but that was exceptional, and would not be maintained in practice. A production however of 45,000 cubic feet per ton had been maintained daily. In this country 38,000 cubic feet per ton had been made out of Shireoaks, Sheepbridge, and similar coals. The generators were not working under the best conditions, owing to low steam-pressure. The heat units of the water-gas varied from 350 to 400 British thermal units per cubic foot.

In starting a fire in the generator (page 408) a layer of coal or coke 2 or 3 feet in depth was put in and ignited at the top, the draught being downwards. When this body of fuel was well ignited, the generator was slowly charged with coal until the top of the fuel bed was above the ports shown in the upper part of the vertical section, Plate 129. To this height the fuel bed was maintained, and the fire need not be drawn for months. The highest heat would be at the bottom, and the fuel bed would be incandescent up to within 6 or 10 inches of the top. The bottom would be cooled by the introduction of steam for water-gas making, and this tended to avoid clinkering. The air drawn in through the feed door at top went down through the fresh coal; and in passing through the hot fuel bed at bottom the tar was decomposed, and the gas went away as producer-gas quite clean, so that it was distributed through pipes for a long distance, as at Messrs. Firth's. In the United States it was carried perhaps 1,500 or 2,000 yards; the distance was only a question of cost. In delivering the producer-gas it was sent through a governing holder; the pressure was fixed at 2 or 3 inches of water, and the flow of the

(Mr. Oakman.)

gas was regulated by an ordinary gas-valve, as it went into the furnace in which it was to be burnt. The working of the furnaces was not affected by draughts or by any change in atmospheric conditions.

As to melting steel in crucibles (page 407), perhaps 3 tons of coke might be taken as a fair average for melting a ton of steel. The water-gas obtained from $1\frac{1}{2}$ ton of coal, of the same kind that was used for making the coke, would melt a ton of steel in crucibles. At the same time there would also be obtained from the same $1\frac{1}{2}$ ton of coal a quantity of producer-gas, which, if applied to re-heating, possessed quite half the value of the $1\frac{1}{2}$ ton of coal, if the latter were burnt direct in the reheating furnace. Considering the question solely as one of cost, and taking the present prices of coke and coal, the economy by the use of water-gas for melting steel in crucibles was fully 75 per cent. in comparison with coke-firing, as stated in the paper. Or taking the number of pounds of coal required to make one pound of coke, and remembering that it required three pounds of coke to melt one pound of steel, while the same work might practically be done with one pound of coal, it would be seen that the percentage of economy named was within the mark.

As to the durability of furnaces using water-gas (page 412), furnaces melting steel in crucibles had been working from four to five months, and were still apparently in as good a condition as at first; they were constructed of the usual furnace brick, and seemed to stand as well as any of the ordinary furnaces that he had seen doing the same work. The durability of the furnace was a question of the adjustment of the heat; and in his own experience of water-gas he had not found that it cut the furnace out. The flow of gas was under perfect control, and the heat could be maintained either at 1,000° or at 5,000° Fahr. as might be preferred, and could be so regulated as not to damage the furnace. As the gas was not regenerated, a much simpler construction of furnace was possible, reducing both the first cost and the cost of maintenance.

In the application of water-gas for all purposes he no more believed than did Sir Lowthian Bell (page 413); but he did find many purposes to which it could be economically applied. If indeed

the solid fuel could be enclosed, and the whole of its heat kept in and utilised, there had yet to be found any economy in the use of gaseous fuel.

To the blast-furnace, the cupola, or the firing of boilers, he should not think of applying water-gas; but it was proving itself a practical and economical fuel for melting steel in open hearth and crucibles, for melting platinum, silver, copper, brass, and other metals, and for welding and smith's work, &c. For puddling it was an excellent fuel. For these and many other purposes water-gas had an advantage over producer-gas. It did not follow however that for every application of gaseous fuel water-gas was the better.

With regard to the freedom from clinker in the generators (page 406), in his own experience in burning soft coal in the generators he had found a great freedom from clinker; which he had attributed largely to the fact that the coal had burned so well and so freely. The first water-gas generator which he had constructed for his own purposes had been for the use of anthracite coal, and the fire had to be broken out three or four times a week. The generators had been fired with coke in different ways. Then he had attempted to burn soft coal with a downward blast; and while there was a little gain, there was also at first a great deal of trouble, and he did not get good combustion at the top of the generator. By now taking in at the top what air was needful for combustion, the coal was burnt at the top freely. It might naturally be supposed that the ash would be at the top, but it was not so; the coal becoming coked worked its way to the bottom. It had been anticipated by a prominent gas engineer in the United States that it would be found impossible to work a process like this, because the ash would all be at the top of the fire, and would prevent proper combustion. In practice however it was found that the combustion was nearly perfect, and the ash was not at the top, but at the bottom.

The President thought there was still a great deal more to be said on this subject, which had been considerably spoken about in England during the last two or three years. As further experiments

(The President.)

were being made, he hoped that a subsequent paper would be given on a future occasion, with fuller statistics than appeared as yet to be available. Meanwhile he moved a vote of thanks to Mr. Oakman for the information furnished in the present paper.

DESCRIPTION OF THE SHEFFIELD WATER WORKS.

By Mr. EDWARD M. EATON, Engineer.

The town of Sheffield is supplied with water by gravitation from the elevated moorlands lying to the west and north-west, as shown in the general plan, Plate 132, the gathering grounds forming part of the eastern slope of the backbone of England. The rainfall has been continuously gauged for the last fifty-four years, and averages rather more than 40 inches in depth per annum. Of this it has been ascertained from actual experience that during a period of three consecutive dry years nearly 20 inches per annum can be collected, stored, and distributed.

The system of Reservoirs may be divided into the High-level and the Low-level, the distinction having reference, not to absolute height above the sea, but to the means available for conveying the water from the storage reservoirs into the various service reservoirs near the town.

High-level Reservoirs.—The High-level reservoirs are situated at Redmires, about six miles in a direct line from the centre of the town, these reservoirs being among the earliest of the large works constructed by the late Water Works Co. They consist of three reservoirs—the Upper, Middle, and Lower Redmires—with the Oaken Clough Dam and Catch-water. They receive the flow from 2,108 acres of drainage area, and have a total storage capacity of 670 million gallons, the gathering ground comprising the upper part of the valley of the river Rivelin. The water from the high-level reservoirs is conveyed down a water course, open for the greater part of its length, but covered in at the lower end, into the Hadfield or Crookes service reservoir having a capacity of more than 21 million gallons, whence the supply is taken for the higher parts of the town.

Low-level Reservoirs.—The Low-level system comprises two reservoirs upon the river Rivelin, originally constructed for mill compensation purposes, in consideration of water taken from the high-level system. Under the Sheffield Water Works Act of 1853 these Rivelin reservoirs reverted to the Water Works Co., compensation to the stream being provided for by the flow, over a notch gauge or weir, of seven cubic feet per second during 24 hours of every working day. The other portion of the low-level supply is composed of four reservoirs in the adjoining valley of the river Loxley, these being the Strines, Dale-Dike, Agden, and Damflask reservoirs. There is also upon the river Rivelin, immediately above the mill-compensation gauge, a small reservoir called the Depositing Pond, constructed for the purpose of regulating the flow of water for the mill gauge. The total capacity of the low-level system of storage reservoirs is more than 3,000 million gallons, details of which are shown in the accompanying Table, which also shows the area of water-shed draining down to each system of reservoirs. The water

Existing Reservoir Capacities, and Areas of Gathering Grounds.

Reservoir.		Capacity.	Gathering Ground.
HIGH LEVEL.		Gallons.	Acres.
Redmires Upper		343,000,000	
Redmires Middle		187,500,000	
Redmires Lower		139,500,000	
Total of High-level . . .		670,000,000	2,108
LOW LEVEL.			
River Rivelin	Rivelin Upper	48,500,000	2,870
	Rivelin Lower	175,000,000	
	Depositing Pond	8,000,000	
River Loxley	Agden	629,000,000	2,999
	Strines	513,000,000	2,890
	Dale Dike	486,000,000	1,089
	Damflask	1,158,000,000	3,747
Total of Low-level . . .		3,017,500,000	13,595
Total of High-level and Low-level		3,687,500,000	15,703

collected in the Strines, Dale-Dike, and Agden reservoirs is conveyed through a tunnel, passing under the high ridge which divides the Loxley from the Rivelin water-shed; and uniting at the Depositing Pond with the water from the Rivelin reservoirs, passes through a conduit and tunnel to the service reservoirs at Crookesmoor lying immediately west of the town.

In the valley of the river Ewden, lying immediately north of the Loxley valley, the Corporation of Sheffield have power to construct two other reservoirs, namely the Broomhead and Moorhall reservoirs, for receiving the flow from a drainage area of 6,496 acres; but these works have not yet been commenced.

Summary of Supply.—The total drainage area of the works is 15,703 acres. The total available water during three consecutive dry years is 19,460,000 gallons per day, of which an average of 9,113,472 gallons per day has to be sent down the streams as compensation water, leaving 10,346,528 gallons per day for the supply of the town and district. It will thus be seen that nearly one half of the available supply of water has to be sent down the rivers for the benefit of the mill owners and other riparian proprietors.

Redmires Middle Reservoir.—In order of date the first storage reservoir constructed was the Middle reservoir at Redmires. This reservoir has an embankment 1,012 yards in length, the greatest depth of water being 36 feet; and it is provided with two overflow weirs or bye-washes, respectively 70 and 104 feet in length. Water is drawn off by means of valves, placed in a masonry shaft and discharging into the lower reservoir, the valve-shaft being connected with the bank by a wooden bridge constructed in 1834. This bridge is now much decayed, and is on the point of being replaced by a bridge made of iron.

Redmires Lower Reservoir.—The next reservoir in point of age is Redmires Lower, constructed in 1847. The depth of water is 29 feet, and the length of the bank is 590 yards. Here both the water for supply and the flood water are conveyed through a valve and overflow shaft into a culvert passing through the bank, means being

provided on the outer slope of the bank for passing surplus or flood water into the Wyming brook and river Rivelin; while the water required for the town is taken into a gauge basin, measured through a notch, and sent down the water course into the high-level service reservoir.

Redmires Upper Reservoir.—The Redmires Upper reservoir, constructed in 1853–4, receives the water from its own gathering ground, and also, by means of a catch-water drain, the additional yield of the Oaken Clough drainage area. This reservoir has a bank 780 yards in length, the water being drawn off by means of two lines of pipes 14 inches in diameter laid through the bank, terminating at their inner end in a vertical cast-iron valve-tower or shaft.

These three Redmires reservoirs may be taken as types of the old practice of reservoir construction in this country. The predominant features are banks of earthwork with a puddle wall in the centre, the depth of water rarely exceeding 40 feet; and the absence or insignificance of masonry or brickwork.

Rivelin Reservoirs.—The same general features distinguish the next two reservoirs to be described, namely the Upper and Lower Rivelin reservoirs. These two reservoirs were constructed under the Sheffield Act of 1845, to be vested in the mill-owners, who had full control over them, and power to draw off water from them as they thought fit. They were of a capacity agreed upon between the Water Works Co. and the mill-owneer; and having a gathering ground far in excess of their storage capacity, a bye-pass channel or river diversion was constructed, by means of which excessive floods were prevented from entering the reservoirs, or when these were full the whole flood from the drainage area was diverted past them. Each reservoir is provided with an overflow weir or bye-wash, and water is drawn from them by means of a pipe 24 inches in diameter.

These five reservoirs, namely the three at Redmires and the two on the Rivelin, were designed and constructed by the late Mr. John Towlerton Leather, who from 1830 to 1865 was the engineering adviser of the late Water Works Co. Since the latter date the

engineers responsible for the large and important reservoirs upon the Loxley have been Messrs. T. and C. Hawksley.

Depositing Pond.—In the Rivelin valley the Depositing Pond, also constructed by Messrs. Hawksley, is principally remarkable for its fine overflow weir and bye-wash, capable of conveying away the heavy floods which are occasionally discharged from the area of nearly 5,000 acres draining down to this point.

Agden Reservoir.—In the Loxley water-shed, the first reservoir constructed was that upon the Agden Dike, having a storage capacity of 629 million gallons, the embankment being nearly 100 feet high and containing 900,000 cubic yards of material. The water is drawn off from the reservoir by means of a valve-shaft and a culvert laid through the bank, controlled by two valves which are worked by gearing upon the top of the shaft. From the outlet culvert the water discharges into a gauge basin, where provision is made by means of a slot gauge or orifice for passing a measured quantity of compensation water down the stream. The measuring opening or slot is made capable of accurate adjustment by sliding jaws of steel, which when adjusted are locked by two padlocks; the key of one is in the hands of the clerk to the mill-owners, while that of the other is kept at the Water Works office; it therefore requires the consent and presence of both parties to make any alteration in the measuring apparatus. The same description of slot gauge is in operation at each of the four reservoirs upon the Loxley.

Strines Reservoir.—The Strines reservoir at the head of Bradfield Dale has a bank 418 yards in length, the water being drawn off by means of a shaft and a culvert through the bank. This embankment, in common with those of the other Loxley reservoirs, has an inside slope of three to one; the outer slope is two and a half to one, and is strengthened by level benchings.

Dale Dike Reservoir.—Immediately below the Strines reservoir is the Dale Dike reservoir, upon the site of, but considerably smaller than, the ill-fated reservoir which was destroyed by the disastrous inundation on 11th March 1864. The embankment which was then destroyed crossed the valley obliquely, about a quarter of a mile

below the present bank; and before the reservoir was completely filled with water a landslip led to a settlement in the outer slope of the embankment, causing the puddle wall to subside and the water to flow over the top of the bank. In a few minutes the reservoir was destroyed, and the valley down to Sheffield was inundated, causing the death of 244 persons, and destruction of an enormous amount of property. The Water Company paid no less a sum than £373,000 in respect of injury and loss sustained, the disaster being happily unique so far as regards this country.

The embankment for the new reservoir was made higher up the valley, in order to avoid the treacherous ground upon which the old bank stood; but it may be interesting to state that the pipes which ran under the old bank, and which were alleged to have caused the disaster, are still in the ground, and are as tight and strong as the day they were laid. The water is drawn out of the present reservoir by means of a tunnel driven through the solid rock round the end of the embankment; two valves are provided, one behind the other, and the gearing for working them is placed in a small house near the overflow weir; the outlet from the tunnel is in a line with the foot of the bye-wash. This reservoir was completed and filled with water in 1875, but was not found necessary to be brought into use until the exceptionally dry year 1887.

Rather more than a mile below this reservoir, and at the junction of the Dale Dike with the Agden Dike at Low Bradfield, is the mill-compensation gauge, over which is passed for the use of the mill-owners a quantity of water equal to ten cubic feet per second during 24 hours of every working day. In a small house alongside this gauge there is a recording machine designed by the writer for the purpose of continuously measuring the water flowing over the gauge bar.

Damflask Reservoir.—Immediately below this mill gauge is the tail end of the largest, and in some respects most important reservoir belonging to this undertaking, the Damflask reservoir, which is the lowest upon the river Loxley, and has a storage capacity of 1,158 million gallons with a depth of water of 85 feet. The water is drawn off by means of two culverts through the bank, each provided

with a valve-shaft on the inner end. Having regard to the great size of the reservoir, the embankment is not long; but the works in connection with it are enormously heavy and costly. When the reservoir is filled with water up to a certain height, it has been ascertained that a band of rock upon the south side allows the water to pass through the joints and fissures, to reappear as a spring at the bottom of the embankment. It was foreseen that this might prove to be the case; but as it was uncertain what the quantity of water passing might be, it was considered better to defer remedial measures until the reservoir was filled and proved. To stop this percolation, a wing trench is being cut through the pervious rock into the underlying shale, which will be filled with puddle, and so stop the water from passing away. This work being now in progress, the Members of the Institution visiting the reservoir will be able to follow the method adopted. At the foot of the embankment is placed the mill-compensation gauge-weir, having three slots or openings similar to those already described; while in a little house adjoining is another recording gauge, similar to that at Low Bradfield.

Distribution.—After leaving the storage reservoirs and being received into service reservoirs at Crookesmoor, the water is distributed throughout the town and district of supply by means of main pipes from 24 inches to 5 inches in diameter, laid in zones. The service pipes are mainly 4 inches in diameter, 3-inch pipes being laid in short streets and courts. The total length of the distributing pipes is nearly 300 miles. The total daily quantity of water distributed is about $6\frac{1}{2}$ million gallons, of which exactly one-third is for trade and manufacturing purposes, or for supplies in bulk to local authorities distributing water themselves.

When water was first supplied to Sheffield under constant pressure in 1869, the daily consumption was 40 gallons per head of the population supplied, of which only about $2\frac{3}{4}$ gallons per head was for trade purposes. Now, and for many years past, the quantity consumed without restriction or limitation, for all purposes other than meter supplies, has averaged not more than about 13 gallons per head per day; this happy result is due to the rigorous rejection, so far

as practicable, of fittings and apparatus of an inferior character, combined with unceasing vigilance in suppressing all unnecessary waste of water.

Self-Recording Gauges.—At each of the service reservoirs a self-recording gauge, similar in construction to those at Low Bradfield and Damflask reservoir, is fixed for the purpose of measuring the water supplied to the town. These recorders have been in use since 1878 ; and the result of their working has been to disclose several facts relating to the supply of water, of a character very interesting to all engaged in the practical management of water works. The diagram, Plate 133, shows the curve of the average draught of water during 24 hours starting from midnight, for the period of twelve years from 1878 to 1889 inclusive ; and by throwing these results into another form, as shown in Plate 134, the hourly percentage on the draught is ascertained. From the latter diagram it is apparent that, so far as Sheffield is concerned, the least draught upon the reservoirs is between three and four o'clock in the morning, the maximum draught being between eleven and twelve noon ; while the fact of the stoppage of work for dinner between twelve and one o'clock is strikingly manifested. The diagram further indicates that in proportioning pipes for town supply, although the average daily flow through the pipes may be taken at 100, yet provision must be made for passing 50 per cent. in excess of this quantity.

In connection with the system of pipes for water supply, it may be interesting to compare the two specimens of pipe exhibited, each being five inches inside diameter. One of these is the modern cast-iron pipe, as now laid in the streets of Sheffield ; the other is a wooden pipe formerly used, which was taken out of the ground during May last, after having probably lain there nearly if not quite a century. These wooden pipes were made upon the Water Works premises, and the last of them was laid about sixty to seventy years ago.

Quality of Water.—The water supplied to Sheffield may be taken as a fair type of the excessively soft upland waters supplied to many

of the large towns in the north of England. The hardness varies at different periods of the year, rarely falling below two degrees of Dr. Clark's scale, and seldom exceeding three degrees. The extreme energy displayed by these soft waters in attacking metals exposed to their action is well shown by the specimens now exhibited of wrought-iron screw-spindle, nuts, bolts, and washers. These have been wholly immersed in the water to a considerable depth for a period of more than forty years; and the manner in which the pure metal has been eaten away is most remarkable. It has been found also that steel blades, such as razors, scissors, pocket and table knives, and also files, suffer complete deterioration to a considerable depth from the surface of the metal, when immersed in the water for several years. This has been proved by the recovery from time to time from the reservoirs of bundles of such steel articles, which had doubtless been placed there in connection with trade outrages in times past. The steel was found to have become converted into plumbago, whole bundles of blades being capable of being scraped away with a penknife. This fact should induce caution in the use of cast steel, when wholly and continuously immersed in water of this character.

The Corporation of Sheffield supply water to more than 320,000 persons. The revenue from water rates is £90,000 per annum. The capital cost of the undertaking, as shown by the accounts to 25th March 1890, has been upwards of £2,115,000.

Discussion.

Mr. Eaton exhibited a large model in relief, showing the entire extent of the drainage areas from which the water was collected by the various reservoirs or carried off by the several rivers. He showed also a collection of specimens of wrought-iron bolts and nuts, &c., which had been deeply corroded by the action of the water; and a number of photographs of the self-recording gauges.

Mr. CHARLES COCHRANE, Past-President, had noticed with much interest the mention made in page 427 of the conversion of steel into plumbago, or the eating away of the metal on exposure to the action of the water during a lengthened period. In the old system of manufacturing cast-iron pipes, now put a stop to from the results of experience, he believed that cast-iron had been used of an exceedingly graphitic character; and the result had been exactly the same. In the course of years, when the pipes were laid in the ground, they had become eaten through, and the carbon could be peeled away with a pen-knife. He was glad to find such testimony borne to the similar effects produced on steel articles. It was a warning not to have recourse to such very gray metal for waterworks purposes; a harder and more close-grained metal was required.

Mr. EDWARD P. MARTIN, Member of Council, mentioned that at the Dowlais Iron Works a boiler had been fed at one time with extremely pure water; it was an ordinary boiler attached to a pumping engine, and was used mainly in dry weather. It deteriorated so rapidly that for a long time it was thought there must be some acid in the water. But on testing the water it was proved beyond doubt that the deterioration was due simply to the extreme purity of the water; for no trace of acid could be detected in it, nor did the slightest particle of grease find its way into the boiler. A few cart-loads of lime were thrown down into the watercourse leading to the feed-water pond; and this being repeated from time to time, there had never been any further trouble from corrosion.

Sir JAMES N. DOUGLASS, Vice-President, had observed cases of extreme deterioration of iron in salt water, where the metal had been entirely converted. One case was that of an old relic which was now preserved in London by the Trinity House, a cast-iron gun recovered at the Eddystone, where the metal was 3 or 4 inches thick. It was found to have been lying in the water about two hundred years, and it was entirely converted into a sort of plumbago, which could be cut into with a knife. It might be interesting

to know that cast-iron was so completely destroyed in salt water within a reasonable period. The action of pure and impure water seemed a puzzle to himself. At the Souter Point electric lighthouse, midway between Sunderland and South Shields, a pair of boilers, made in 1870 and working ever since, were as clean inside as on the day they were put down. They were fed from two large tanks, which were supplied from a rain-catch; and it might therefore be assumed that the water was pure. Everything was clean; great care was taken; very little oil was used in the cylinders, and that was tested for freedom from acid. It therefore seemed extraordinary to him to hear pure water spoken of as destroying boilers; he did not see how this could be.

Sir Lowthian Bell, Bart., Past-President, deprecated the danger of drawing general conclusions without prolonged observations. It was well known that locomotive boilers corroded at certain points. There was evidently some action quite independent of the character of the water or the character of the iron or steel, because with the same water and the same iron or steel there was corrosion at certain points and not at others in the same boiler. On the North Eastern Railway the branch to the Rosedale mines was worked by separate locomotives confined to that branch. At first there was nothing but moor water to be got for the boilers, which was very soft and pure; and the boilers failed from using it. Afterwards a spring was discovered on the moor, and a small supply of impure water was obtained from it and mixed with the pure water from the moor; and thenceforth all further corrosion of the boilers ceased. In the long wrought-iron screw-spindle exhibited by the author it would be seen that the action of corrosion or solution had not been going on uniformly, as it would do in the case of a soluble substance. If a lump of sugar were put into water, the solution would probably go on uniformly over its whole surface, unless it were retarded at any particular spot by an accumulation of partially saturated water. In the case of the wrought-iron screw-spindle it would be seen that there was something in connection with the solution of iron by water which was not of a normal character. That might proceed from layers of cinder at the welding of the iron,

(Sir Lowthian Bell, Bart.)

setting up a local electrical action, and promoting solution where the cinder was in contact with the adjoining pure metal. He could confirm what Sir James Douglass had said, having himself seen a gun of even greater thickness almost entirely corroded by sea-water. It was not pure water alone that produced corrosion. Very impure water containing $2\frac{1}{2}$ per cent. of saline matter acted in a similar way, and might be even more energetic in its action on iron than soft water. It was a mistake to assume that rain water was perfectly pure; it contained a certain quantity of ammonia, but instead of being acid in its characteristics it was alkaline.

Mr. EDWARD B. MARTEN, Member of Council, said it had been usual to consider gravitation waterworks as coming more within the province of the civil than of the mechanical engineer, because there were no large pumping engines in use; but in such works there were nevertheless many things of great mechanical interest.

At the beginning of the paper it was mentioned that the average annual rainfall for the last fifty-four years amounted to 40 inches, and that during three consecutive dry years nearly 20 inches per annum could be secured. It was not stated however what the rainfall was during those three dry years; and he wanted to know what was the proportion secured of the rainfall in the three dry years, not of the average rainfall during the fifty-four years. The members who purposed visiting the works on the following day would do well to examine beforehand the model now exhibited, which had been made by Mr. James B. Jordan; they would here see at a glance the general arrangement of the works and the position of the reservoirs, not only in plan but in elevation. It was this excellent model that had induced him to get Mr. Jordan to make a similar one for the South Staffordshire district exactly on the same lines, and the latter had proved extremely useful.

The gauging apparatus described in the paper appeared to him to be not only a beautifully adjusted contrivance for calculating the quantity of water that went down the river in compensation, but even still more useful to waterworks engineers for measuring the quantity supplied to a town. During the time when the constant and the

intermittent systems were much on their trial, he had been in charge under his brother Mr. Henry J. Marten of the waterworks at Wolverhampton, which he believed was at that time the only town that could make similar experiments as to how much water was used per hour during the day. There were no reservoirs, and the engines had continuously to supply what was wanted; and the diagram now exhibited in Plate 134 almost represented what he had then found: namely that during the still hours of the night the water supplied was practically nil, the engines sometimes not moving at all; and that during the hours just before and after the dinner time there was most used, and there was always a lull at dinner time. The data then obtained were shown in Plates 135 and 136, of which Plate 135 represented the average consumption of water in each hour during a week's observations taken in April 1850 for Mr. Henry J. Marten's evidence before the General Board of Health, for their report on the water supply to the metropolis. There were no observations from 9 p.m. to 6 a.m. beyond the total consumption during that interval, from which the lines had accordingly been plotted in the diagrams. These he believed had hitherto been almost the only figures published, and they had been alluded to in text-books as showing how much water was used per hour. Until now he had not known of any gravitation works that could so measure the water as to be able to show with such accuracy what was the hourly consumption in a large place like Sheffield. By means of the diagram now exhibited, Plate 134, it was pointed out by the author that 50 per cent. more water passage should be provided by larger pipes than the mere average of the daily flow would require, because of the large draught of water during the hours in the middle of the day. But it would be remembered that at the time he was speaking of, forty years ago, it had been usual to calculate the size of the pipes on the assumption that the whole of the water was to be delivered in six or eight hours, because the intermittent supply was then adopted. The experiments he had referred to had been tried in order to show that there was no need to dread the consequences of constant supply, and that only 90 or 100 per cent. increase in the size of the pipes would

(Mr. Edward B. Marten.)

be needed, Plate 136. Under the intermittent system London was formerly supplied with pipes so large that it was supposed each district would be supplied with water in two hours; but he had no doubt it was the fact that with the present constant supply the pipes in London were needed only one-fourth of the area which they were originally intended to be, and which was thought necessary when the intermittent system prevailed. For mechanical engineers, especially those who had to do with waterworks, this appeared to him to be one of the most interesting points that could engage their attention.

He had had some experience of pipes becoming like plumbago, in consequence of their having been laid in newly formed ground made up with ashes. In less than two years they could be cut through with a pen-knife; but that result had nothing to do with the purity of the water. The wooden pipe exhibited was a very interesting specimen; he had picked up similar wooden pipes in Wolverhampton. In the mines in South Staffordshire a wooden pump-tree of 10 inches inside diameter had been found, in which it was curious to find the bore so true. It was bound round with iron bands to keep it together. The reason why the large cast-iron pumping pipes were still called pump-trees he supposed was because they had originally been made from trees. For a long time they used to be cast with bars or ribs round them, as if to imitate the iron bands round the old wooden pipes. The specimens which he had found were made of oak. At Wolverhampton a brass ferrule was driven into the wooden pipes wherever there was a branch to be led off to a house.

He asked what was the effect of the Sheffield water on the lead pipes which he presumed were used in private houses; and also whether wrought-iron pipes were employed.

It would also be interesting to engineers to know something more as to how the daily consumption had been brought down so low as only 13 gallons per head; and what arrangements were made to secure so little waste.

Mr. GEORGE D. HUGHES asked what was the average pressure of the water delivered in Sheffield. He presumed that it was supplied

for use in case of fire. He should also like to know whether it was supplied for motive power, for driving hydraulic engines or any other purposes; and whether any meters were used for measuring the water under high pressure for manufacturing purposes.

Mr. RICHARD HOSKIN said it would be interesting to know also to what extent water under pressure was used in Sheffield for various manufactures or for any other purposes.

Mr. ARTHUR PAGET, Vice-President, asked how the old wooden pipes, like the specimen exhibited, had been jointed.

With regard to corrosion, he knew a boiler close to his own works in Loughborough which was fed with the purest soft water, and there was hardly any corrosion, simply because care was taken not to put acid, under the name of grease, into the boiler.

Mr. HENRY J. SPOONER mentioned that a few years ago he had had occasion to cut away part of a Perkins tubular boiler which had been working with distilled water for thirty-five years, and there was really no appearance of oxide of any kind. The water appeared to have had no effect on the inner surface of the tubes.

For measuring water under pressure he had had under his care for some time a French meter of the positive or piston kind, which he thought would probably prove to be the most perfect yet produced of that kind.

Mr. HENRY DAVEY mentioned that at the Leeds infirmary there were some Lancashire boilers used as hot-water boilers to circulate the hot water for heating purposes; they were fed with water from the town mains, which was slightly peaty, and was said to be exceedingly pure; but until a little lime was used in the boilers the joints could not be kept tight. The steam boilers used for motive power were not affected in the same way; and no doubt the reason for the hot-water boilers failing was the greater quantity of water passing through them than through the steam boilers. As to the leaking of boilers said to be fed with pure water, he thought it often

(Mr. Henry Davey.)

happened that so-called pure water contained a certain amount of acid; and no doubt the Leeds water did contain some vegetable acid.

The PRESIDENT said he had certainly found the local effects of corrosion in boilers exactly as described by Sir Lowthian Bell (page 429); and corrosion occurred in some boilers, but not in others. In the boilers of sea-going vessels, under the old conditions with jet condensers, all the internal portions of the air-pump were almost invariably converted into plumbago, so much so that the valves would ultimately come out bodily. Marine engineers had now, as was well known, gone to the other extreme by using practically pure water. At first the pure water had been almost worse than salt water, because in many cases the engineer could not be prevented from blowing down, as he had previously been in the habit of doing with salt water. The moment a certain degree of saturation was reached, it was thought necessary to blow down; and the boilers were kept so exceedingly pure that it was impossible to get any scale on them at all. At the time that he was living in Cardiff, several of his pupils who went to sea got into difficulties with the surface-condensing engines, and could not get the boilers to scale. Perhaps one boiler would scale, while the other would not scale at all. The advice he had given was, before going to sea to put a basket containing about two bushels of unslaked lime into the bottom of the boiler, leaving it there till it was gradually dissolved away. The result was that when the vessel returned the boiler was found to be coated with a thin black scale. Nothing was required but a hose pipe to wash the boiler out; no hammer-scaling was needed. As soon as ever any scale was seen to be breaking off, another bushel of lime was put in. In that way boilers had been kept going at sea for twelve months, without doing anything more than washing them out with a hose. There was no deposit at all. The same action went on in the air-pumps as before, but it must have been from a totally different cause, either from salt-water corrosion or from some other chemical action; whereas the boiler corrosion had been from want of salt, or want of something else in the water, which was as pure as that in Sheffield. Further north also in the neighbourhood of

Durham it was all peat water, almost red and not appetizing to look at, but perfectly pure water. In the old-fashioned way of working marine engines with salt water and the jet condenser, the corrosive action undoubtedly took place to almost the same extent that it now took place with the surface condenser.

Mr. Cochrane was afraid there was some danger of pure water getting the blame which it ought not to have for the corrosion; and he considered there was no reason to fear the use of pure water. Some of the mischievous corrosion he thought was due to the acidity of the oils formerly allowed to find their way into the boilers; this might be corrected by a dose of alkali, caustic soda being the most suitable for the purpose.

The President said no doubt the quantity of grease that was squirted into the cylinders at sea was simply absurd; and in his own practice he had found the less grease of any kind that was put into the cylinders of marine engines the better. It was of no use putting ordinary oils into the present engines, because the heat of the high-pressure steam now used simply carbonized all the oil. In the working of a pair of marine engines of 100 H.P. nominal, built by Hawthorn of Newcastle-on-Tyne, he had directed the engineer on starting for a voyage to the Mediterranean to fill the cylinder oil-cups with water, and let that go into the cylinders whenever they seemed to want a little grease, and to use no oil at all. On the return of the vessel from her voyage the cylinders were found to be as smooth as glass, and the valves also were in perfect order, no oil whatever having been supplied into the cylinders or valve-chests.

Mr. Eaton, in reply, said he could mention one or two facts which would show how the Sheffield water behaved itself in boilers in Sheffield. A Lancashire or double-flued boiler, without Galloway tubes, 28 feet long and 7 feet diameter, had now been in use forty years, and he was told it was as good as on the day when it was put down. It had never been fed with anything but Sheffield water.

(Mr. Eaton.)

That experience he thought was in itself sufficient testimony to the quality of the water for boiler purposes. Then again a large firm of manufacturers in Sheffield had gradually introduced the use of the town water for all their boilers, of which they now had forty or fifty on their premises. Moreover the two railways running through Sheffield, the Midland and the Manchester Sheffield and Lincolnshire, were both of them using a continuously increasing quantity of the Sheffield water for their locomotives; they found indeed that it paid them to send their engines to Sheffield to take in water in preference to other places in the neighbourhood, and the water bills of both these railways had gone on increasing to an important extent every year. These facts showed that water users were quite alive to the good qualities of the water.

As to the question of pure versus impure water, a great deal depended upon the interpretation of the word "pure." Sheffield water had only from 2 to $3\frac{1}{2}$ degrees of hardness according to Dr. Clark's scale, in which one degree of hardness was equivalent to one grain of carbonate of lime dissolved in one gallon of distilled water: so that it might be regarded practically as pure water, not indeed in the sense in which a chemist would use the expression, but certainly in the sense in which a mechanical engineer would use it. Allusion had been made to the Leeds water (page 433), which he knew well; it was very similar to the water supplied to Sheffield, but was a trifle harder; it might be fairly looked upon as pure water for a town supply.

The action of the water upon wrought-iron pipes (page 432) was such that practically they could not be used in Sheffield at all. They became completely bunged up inside, and were frequently eaten through in three years. Cast-iron pipes lasted very well; the only difficulty with them was that tubercles of oxide of iron in combination with peaty matter formed on the inside of the pipes. The cause of this formation was at present obscure. Pipes had been taken out after three or four years' use, during which they had been subjected to a pressure equal to 400 feet head of water with a stream of water constantly flowing through them, and the whole inside had been found to be pitted over with these rust tubercles. When they

had been scaled off with a pen-knife, the original black glaze had been found to be perfect underneath; there had therefore been no communication between the metal of the pipe and the rust tubercles that formed inside it. Upon lead pipes the action of the water had been a vexed question in Sheffield for the last year or two. Unquestionably it did act upon lead. The popular explanation was that the water was so pure and so hungry that it would eat anything it came in contact with; and if the first thing upon which it could satisfy its hunger was the inside of a lead pipe, it was ready to take that. But the Sheffield water was by no means so energetic in its action upon lead as the water of some other places. The Keighley water, even when it had been treated with limestone, acted much more energetically upon lead than the Sheffield water in its raw state. The Sheffield water was now being treated with chalk in a state of fine subdivision for the purpose of preventing that action, and recent experiments upon new lead pipe had shown that the treatment was successful; although it could not be said that the water did not take up a little lead, yet certainly there was no serious action. In this direction however finality had not yet been reached, because the chalk process had thus far been tried only during the period when the action upon lead was naturally falling to a minimum. The action dropped down from February to July, and from July it went on increasing again to November. Between November and February the lead-dissolving power of the water oscillated, but it maintained practically a constant maximum. How therefore the process of treating the water with chalk would answer during the next six months, there was as yet no experience; time alone would show.

As to how steel had been acted on by the water, it was well known that there had formerly been trade disputes in Sheffield, and a summary way of settling them had been adopted. The raw goods in an incomplete state of manufacture had been stolen, and thrown into the waterworks reservoirs; and years afterwards, when the water had been run down, the packages of goods had been found, and the curious action of the water on the steel had been observed. He had found bundles of files forged and ground, but not cut; and the point of a pen-knife could scrape nearly one-sixteenth of an inch into the steel,

(Mr. Eaton.)

and the metal came away as a fine black powder, exactly like cutting a lead pencil. The faces of cast-iron valves were acted upon in just the same way, and practically to the same extent. When they had been thirty or forty years in the water, they could be cut into with a pen-knife to about one-sixteenth of an inch. So with pen-knife blades and table cutlery; naturally their thin edges had gone most. The blade of a knife could be cut into nearly half way through from the thin edge. The articles were often tied up in bundles with iron wire; and in the inside of the bundle, where the water could not get at them so freely, the action was much less. It seemed clear therefore that some action took place quite on the surface of the metal.

As to the failure of cast-iron pipes owing to the ground in which they were laid, that was quite another matter. Cast-iron pipes had been found in some parts of Sheffield, like those mentioned by Mr. Marten (page 432), quite corroded through in from two to three years. That was caused by the ashes that were used so largely round Sheffield for constructing roads; and he had no doubt it was due to the formation of sulphuric acid, which attacked the cast-iron pipes externally and worked its way into the metal. It could be seen, on breaking a pipe, how far the action had gone, by a difference in the tint of the metal. There was also this curious fact, that if the externally corroded pipes, although soft—so soft that they could be drilled through with a pen-knife—were left exposed two or three days to the atmosphere, they became hard again, and a knife could no longer touch them. He asked whether the cannon referred to by Sir James Douglass (page 428) had in like manner become hard again.

Sir JAMES N. DOUGLASS replied that it had hardened sensibly since it was taken out of the water, but not to any great extent.

Mr. EATON suggested, in regard to the action of the Sheffield water upon wrought-iron, as illustrated by the valve-spindle exhibited and the specimens of corroded nuts and bolts, that the lines of metal which were left standing out so sharply were in all probability due to a little more silica being contained in those parts of the metal:

the purer iron had been dissolved out between, and the iron containing a little more silica had been left behind in that way.

The average pressure of the water (page 432) must of necessity vary greatly in a town having the physical configuration of Sheffield in regard to levels. As an average over the whole town it was endeavoured always to maintain as far as possible a pressure of a column of water equal to from 150 to 200 feet head. The lowest levels were mostly under a pressure of 300 feet, but wherever possible this was reduced to 200 feet head, which was a very good working pressure. The minimum pressure was kept as far as possible at not less than 60 feet, which was about as little as would adequately supply water to the top storeys of houses in the higher parts of the district. Here and there, where the houses came closer to the service reservoirs, the pressure might be a little below 60 feet, say 50 feet as the minimum. The maximum preferred was not more than 300 feet head, though in some isolated spots there was a pressure of over 400 feet; but this was dangerous and destructive, and no lead pipes or fittings would long withstand so high a pressure.

As to the supply of water for motive power (page 433), hydraulic motors were supplied direct from the mains. The supply pipes were usually 3 or 4 inches in diameter, according to the size of the motor, and were coupled direct to the mains; the motors worked with the water under the pressure that existed for the time being in the town mains. After the water had done its work in the machine, it passed away through a meter and was measured on the outlet side, so that the machine should derive the full benefit from the pressure in the pipes.

As to high-pressure meters (page 433), that was a very vexed question. There were high-pressure meters that gave good results; but there was only one way to determine accurately what a high-pressure meter would do, and that was to try it in actual daily work. No testing with a measuring tank would give results that could be relied upon for actual work. For ordinary purposes in the supply of manufacturers and others taking a supply by meter, the low-pressure meters were used, having a mechanism precisely analogous to that of a gas-meter, and differing only in the mode of operation.

(Mr. Eaton.)

A gas-meter measured by the levity of the gas turning a drum in one direction; a low-pressure water-meter measured by the gravity of the water turning a drum in the other direction. This was only a popular explanation of its action, but it would suffice to show that it gave an actual measurement, by filling as it were a pint pot, turning it over, and registering the number of times it was turned over. High-pressure water-meters were used under special conditions. The high-pressure meter mostly used in Sheffield was the Siemens inferential meter. It was admittedly not as trustworthy as the positive or piston meter, but for convenience there was probably no meter equal to it: it was light, compact, and portable, and not so liable as some meters to be damaged by frost. One great objection to high-pressure meters, particularly in northern towns, was the damage occurring when there was a severe frost. He had known as many as 140 meters broken from that cause in one night, smashed and good for nothing; whereas he had known low-pressure meters frozen for weeks, and not any the worse at the end of that time.

A question had been asked (page 433) as to the mode of jointing the wooden pipes. It would be observed that one end of the pipe was tapered off to form a spigot; the tapered end was driven into the socket end of the next pipe, which was coned hollow to receive it, just sufficiently to enable a packing of wool to be bound round the spigot end. When these pipes were now drawn out of the ground, many of them having been in for a century and none less than sixty years, the wool packing was found to be still as perfect as when it was put in; and so far as could be judged by snapping the fibres between the fingers, it was stronger than any wool made at the present time.

In reply to Mr. Marten's enquiry (page 430) about the amount of the rainfall during the three consecutive dry years referred to at the beginning of the paper, the three dry years alluded to were 1863–4–5, during which the average rainfall was about 35 inches per annum; the average quantity actually collected off the gathering ground during those three years was nearly 20 inches per annum, the loss by evaporation and absorption being therefore 15 inches.

The great waste of water which ensued upon the introduction of the constant supply had been remedied by the abolition of

underground cisterns and old and defective types of fittings and apparatus. Regulations were enacted prescribing the nature, construction, strength, and application of pipes, taps, and apparatus; and to the rigid enforcement of these regulations, combined with unceasing vigilance in inspection, was due the fact that during the unprecedentedly dry year 1887 no town in the United Kingdom had had a better supply of water than Sheffield, or had been so free from anxiety with regard to the continuance of the supply.

Attention had been drawn by Mr. Marten (page 430) to the model now exhibited, showing the configuration of the ground round Sheffield and the system of reservoirs; and there was a still better model in the Mappin Art Gallery, Sheffield, which had been prepared for the parliamentary campaign of 1887 when the corporation of Sheffield acquired the works from the old company: it was a much larger and more complete model, and the Members he was sure would be much interested in inspecting it.

The President said the Members had already anticipated by their hearty applause the vote of thanks which he had now the pleasure of proposing to Mr. Eaton for his paper.

EXCURSIONS.*

On TUESDAY AFTERNOON, 29th July, after luncheon in the Cutlers' Hall by invitation of the Local Committee, the following Works in Sheffield were opened to the visit of the Members, as also on Wednesday afternoon. Descriptions of these are given in pages 447–465.

Messrs. Chadburn Brothers, Optical and Mathematical Instrument Makers, Albion Works, Nursery Street.

Messrs. Cocker Brothers, Steel-Wire Mills, Nursery Street; and Fitzalan Steel Works, Effingham Road.

Messrs. Dickson Brothers and Co., Waverley Steel and File Works, Effingham Road.

Messrs. Hawksley Wild and Co., Brightside Boiler and Engine Works, Savile Street East.

Messrs. William Hutton and Sons, Silversmiths, 146 West Street.

Messrs. Samuel Laycock and Sons, Horse-Hair Cloth Works, Portobello Place; and Railway-Carriage Fittings Works, Victoria Street.

Mappin Art Gallery and Museum, Weston Park, Western Bank.

Messrs. Mappin and Webb, Electro-Plate and Cutlery Works, Norfolk Street.

Mr. Thomas Nash, Sheffield Testing Works, Blonk Street.

Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Wicker.

Messrs. Joseph Rodgers and Sons, Cutlery Works, 6 Norfolk Street.

Ruskin Museum, Meersbrook Park.

Messrs. Seebohm and Dieckstahl, Steel Converters and Refiners, Dannemora Steel Works, Willey Street.

Sheffield Technical School, St. George's Square.

Messrs. Spear and Jackson, Edge-Tool Manufacturers, Ætna Works, Savile Street East.

Messrs. Tilghman's Sand-Blast Co., Bellefield Works, Bellefield Lane.

Messrs. Walker and Hall, Silversmiths and Cutlers, Electro Works, Howard Street.

In the evening the Institution Dinner was held in the Cutlers' Hall, by kind permission of the Master Cutler, Mr. S. G. Richardson. The President occupied the chair, and the following Noblemen and

* The notices appended of the various Works &c. visited in connection with the meeting were kindly supplied for the information of the Members by the respective proprietors or authorities; some of them have been abridged from descriptions which appeared at the time in *Engineering*.

Members of Parliament were invited, but were unable to accept the invitation:—His Grace the Duke of Norfolk, K.G.; His Grace the Duke of Devonshire, K.G.; His Grace the Duke of Rutland, G.C.B.; His Grace the Duke of Portland; His Grace the Duke of Newcastle; the Right Honourable the Earl Fitzwilliam, K.G.; the Right Honourable the Earl Manvers; the Right Honourable the Earl of Wharncliffe; Mr. A. H. D. Acland, M.P.; Mr. E. Ashmead Bartlett, M.P.; the Honourable Bernard J. S. Coleridge, M.P.; Sir Frederick Thorpe Mappin, Bart., M.P.; the Right Honourable A. J. Mundella, M.P.; Mr. C. E. Howard Vincent, C.B., M.P.; Mr. Henry Joseph Wilson, M.P.; Mr. C. B. Stuart Wortley, M.P. The following Guests accepted the invitations sent to them, though some were unavoidably prevented at the last from being present.

Reception Committee.—His Worship the Mayor of Sheffield, Alderman J. B. Jackson, J.P., *Chairman.* The Master Cutler, Mr. S. G. Richardson, *Vice-Chairman.* Mr. Robert A. Hadfield, *Honorary Treasurer.* Professor William Ripper and Mr. R. Heber Radford, *Honorary Secretaries.* Mr. George Addy; Mr. Harry Allcard; Mr. William Edgar Allen; Mr. Thomas Andrews, F.R.S.; Professor John Oliver Arnold; Mr. Emerson Bainbridge, J.P.; Mr. W. F. Beardshaw; Mr. Charles Belk, J.P.; Colonel J. E. Bingham, J.P.; Mr. Thomas Bradbury; Mr. Arthur M. Chambers, J.P.; Mr. Charles Edward Chrimes; Alderman William J. Clegg, J.P.; Mr. Ralph Collenette; Mr. Thomas F. Craven; Mr. George Dawson; Mr. James W. Dixon; Mr. Frederick Fowler; Mr. William Frost; Mr. Robert S. Hampson; Mr. George William Hawksley; Mr. C. H. Gilbert Hay; Councillor E. E. Holiday; Mr. Richard Hoskin; Mr. S. Earnshaw Howell; Mr. H. Linley Howlden; Mr. Herbert Hughes; Mr. W. R. Humphreys; Alderman Michael Hunter, J.P.; Mr. H. Walter Ibbotson; Mr. Herbert Ingold; Mr. Alexander Jack; Mr. Joseph Jackman; Mr. Joseph Jonas; Mr. Albert Jowitt; Mr. Charles A. Kirkby; Mr. William S. Laycock; Mr. Edwin Leadbeater; Mr. John Daniel Leader; Mr. Arthur Lee; Mr. J. Grayson Lowood; Mr. William M. MacBrair; Mr. J. E. Mathewson; Mr. William McGillivray; Mr. Thomas Nash; Mr. Samuel Osborn, J.P.; Mr.

William F. Osborn; Mr. Henry W. Pawson; Mr. William Kirkby Peace, J.P.; Mr. J. L. Potts; Mr. William Radcliffe; Mr. Benjamin M. Renton; Mr. Charles Edward Rhodes; Mr. Richard Robinson; Mr. Robert Schott; Alderman Richard Searle; Councillor George Senior; Mr. Ambrose Shardlow; Mr. Frederick H. Stacey; Councillor John Sutton; Mr. J. H. R. Tasker; Mr. Joseph Trippett; Mr. Charles F. Wike; Mr. Thomas Wilkinson; Mr. J. Wycliffe Wilson, J.P.

Firth College.—Professor W. M. Hicks, M.A., F.R.S., Principal; Mr. Ensor Drury, Registrar and Secretary.

Authors of Papers.—Mr. George Addy; Mr. Emerson Bainbridge, J.P.; Mr. Bernard Dawson; Mr. Edward M. Eaton; Mr. R. N. Oakman, Jun.; Mr. C. P. Sandberg; Captain Charles J. Stoddart, J.P.

The Venerable John Edward Blakeney, D.D., Archdeacon and Vicar of Sheffield; Mr. John Henry Ainley; Mr. Charles Allen; Mr. H. Allen; Mr. H. Herbert Andrew; Mr. J. H. Barber; Mr. William Burdekin; Mr. Benjamin F. Cocker; Mr. John Y. Cowlishaw, J.P.; Mr. Alfred Craven; Mr. John C. Duncan; Mr. George Eskholme, J.P.; Mr. Lewis J. Firth; Mr. George Hall; Mr. John Francis Hall; Mr. Joseph Hall; Mr. Henry Hart; Mr. John Head; Mr. Joseph Bennett Howell; Mr. J. Rossiter Hoyle; Colonel Herbert Hutton; Mr. William Jessop; Mr. William Edward Laycock, J.P.; Mr. George Francis Lockwood, President of the Chamber of Commerce; Mr. Frank Mappin; Mr. Edwin H. Marples; Mr. Edward Thomas Moore; Mr. Henry Peech; Mr. Charles Dunstan Pettinger; Mr. John William Pye-Smith, Town Clerk; Mr. Edward Reynolds; Mr. John Rodgers; Mr. Maurice G. Rodgers; Mr. Thomas George Shuttleworth, Secretary of the Botanical and Horticultural Society; Mr. Arthur Simonson; Mr. G. Jackson Smith; Mr. Thomas W. Sorby; Mr. Alfred E. Stayner; Mr. John Edward Townsend; Mr. Edward S. Tozer; Mr. Herbert Unwin; Colonel T. E. Vickers, J.P.; Mr. A. E. Wells; Mr. John K. Wilson; Mr. Robert Woodward.

The President was supported by the following Officers of the Institution:—*Past-Presidents*, Sir Lowthian Bell, Bart., F.R.S., Mr. Charles Cochrane, and Mr. Jeremiah Head; *Vice-Presidents*, Sir

James N. Douglass, F.R.S., and Mr. E. Windsor Richards; *Members of Council*, Mr. Samuel W. Johnson, Mr. John G. Mair-Rumley, Mr. Henry D. Marshall, Mr. Edward P. Martin, Mr. William H. Maw, Mr. Benjamin Walker, and Mr. J. Hartley Wicksteed.

After the usual loyal toasts, the President proposed "The Town and Trade of Sheffield," which was acknowledged by his Worship the Mayor of Sheffield, Alderman J. B. Jackson, J.P. The toast of "The Cutlers' Company," proposed by Sir James N. Douglass, was acknowledged by the Master Cutler, Mr. S. G. Richardson. The toast of "Firth College" was proposed by Mr. Jeremiah Head, and acknowledged by the Principal, Professor W. M. Hicks. Sir Lowthian Bell, Bart., proposed the toast of "The Reception Committee," which was acknowledged by the Honorary Treasurer, Mr. Robert A. Hadfield. The toast of "The Honorary Secretaries," proposed by Mr. J. Hartley Wicksteed, was acknowledged by Professor William Ripper and Mr. R. Heber Radford. The Mayor proposed the final toast of "The President," by whom it was acknowledged.

On WEDNESDAY AFTERNOON, 30th July, after luncheon in the Cutlers' Hall by invitation of the Local Committee, an Excursion was made in special free brakes provided by the Local Committee to visit Nunnery Colliery (pages 465–7) under the guidance of Mr. Emerson Bainbridge.

In the evening the Members were invited by the Local Committee to a Conversazione in the Cutlers' Hall, where they were received by the Mayor and Mayoress, the Master Cutler and Mrs. Richardson, and other members of the Local Committee.

On THURSDAY, 31st July, two alternative Excursions were made.

By special free brakes provided by the Local Committee the Sheffield Water Works were visited (pages 419–427) under the guidance of Mr. Edward M. Eaton, Engineer. The Members were invited by the Local Committee to luncheon at Dale Dike Reservoir.

By special free train provided by the Local Committee an Excursion was made to the Tinsley Steel and Iron Works, the Yorkshire Engine Works, Aldwarke Main Colliery, and the Parkgate Iron and Steel Works. At each place the Members were hospitably entertained by the proprietors. At the Tinsley Steel and Iron Works (page 467) they were received and conducted through the works by Mr. Thomas Wilkinson, Managing Director. At the Yorkshire Engine Works (pages 467–8) they were under the guidance of Mr. Robert S. Hampson, Manager. At Aldwarke Main Colliery (pages 468–9) the surface works were inspected under the guidance of Mr. C. E. Rhodes, Manager; by whom afterwards a number of tests of different safety-lamps were shown in the apparatus of his design, similar to that used in the experiments made by the Royal Commission on accidents in mines. At the Parkgate Iron and Steel Works (pages 396–400), where the Members were received by Mr. Charles J. Stoddart, Managing Director, they witnessed the running of 25 tons of steel from one of the open-hearth furnaces into a 30-ton ladle, from which it was delivered into the ingot-moulds; and also the rolling of ingots into slabs, and then into plates and bars. Three large plates recently rolled were shown: one 50 feet by $5\frac{1}{2}$ feet and $\frac{7}{8}$ inch thick, weighing 4·42 tons; another $20\frac{1}{2}$ feet by $11\frac{1}{3}$ feet and $\frac{7}{8}$ inch thick, weighing 3·75 tons; and the third $11\frac{3}{4}$ feet diameter and 1 inch thick, weighing 2·10 tons.

On FRIDAY, 1st August, two alternative Excursions were made, each by free conveyances provided by the Local Committee, by whom the Members were invited to luncheon and otherwise hospitably entertained.

By special brakes one party under the guidance of Mr. R. Heber Radford, Honorary Local Secretary, visited Chatsworth, the seat of the Duke of Devonshire, and Haddon Hall, the property of the Duke of Rutland. At Chatsworth they were received by the Honourable Victor Cavendish, by whom they were conducted through the House and the grounds adjoining.

By special train to Worksop and thence by brakes another party under the guidance of his Worship the Mayor of Sheffield, Alderman J. B. Jackson, J.P., Chairman of the Reception Committee, visited the "Dukeries," arriving first at Welbeck Abbey, the seat of the Duke of Portland, where they were received by Mr. Frederick J. Turner, the Agent, and his son, Mr. Warner Turner, the Secretary. After visiting the gardens, greenhouses, pleasure grounds, riding school, tan gallop, and tunnels, the drive was continued through part of Sherwood Forest, passing Clumber Park, the seat of the Duke of Newcastle, and Thoresby, the seat of Earl Manvers.

THE SHEFFIELD TECHNICAL SCHOOL.

This School, situated in St. George's Square, was erected in 1885 by private subscription. The town of Sheffield however has recently adopted the provisions of the Technical Instruction Act, and the school is now assisted by the rates. Courses of instruction are provided in applied science to both day and evening students, a special feature being made of the subjects of steel and iron manufacture and mechanical engineering. The complete course of study in each department extends over three years.

The metallurgical laboratory is equipped with the most modern apparatus for metallurgical analysis, more especially with appliances for the rapid and accurate chemical examination of iron and steel, fuel, and refractory materials. A small steel works has been erected, including melting-holes, pot-house, malleable-iron furnace, &c. An iron foundry, and a 25-cwt. open-hearth furnace with three systems of gas-producing, are now being built. The instruction is conducted on a thoroughly practical scale, and includes mixing, melting, casting, and chemically and mechanically testing various qualities of steel and iron.

The mechanical engineering department is also equipped with all the necessary appliances for the education of mechanical engineers. The complete course includes attendance at lectures and classes,

experimental work in the laboratories, and practical work in the workshops and drawing office. The workshop course, though not intended to supersede the practical training which can be obtained only in the engineering factory or workshop, serves to familiarize students with the construction and use of tools, and with the principles upon which these depend, and with the ordinary workshop operations of mechanical engineering. The experimental work in the laboratory is of a practical and useful kind, affording information which cannot as a rule be obtained in works, for want of opportunity or appliances. The laboratory is fitted with a vertical tubular steel boiler; a compound steam-engine capable of indicating 50 horse-power, and designed to work under a variety of conditions for illustrating steam-engine economy; a 50-ton Buckton testing machine; and a 4-H.P. Stockport gas-engine. The machine shop contains lathes, planing, shaping, slotting, and drilling machines, and all the necessary shop and bench tools. The wood-work shop contains benches to accommodate twenty-four students working at one time, and six wood-turning lathes driven by steam power. The smith's shop contains appliances for giving instruction in forging, welding, hardening, tempering, &c. The drawing office is one of the largest and best equipped in the country. Several other branches of instruction are provided for evening students.

Professor William Ripper is the Principal of the School and Professor of Engineering; and Professor J. O. Arnold, F.C.S., is the Professor of Metallurgy.

NURSERY WIRE MILLS.

These works, situated in Nursery Street, are the property of Messrs. Cocker Brothers, who, as manufacturers of crucible-steel wire since 1752, confine themselves now to the highest classes of wire, of which the following four descriptions are made:—first, for lace needles and stocking-loom needles; second, for hand-sewing and sewing-machine needles; third, for watch and clock parts; fourth, for all kinds of spiral-coil springs. From the last is made every kind of

spiral springs suitable for colliery and engineering purposes; a colliery-cage bumper-spring has been tested at local collieries with excellent results. All kinds of drawbar and valve springs are also made; and Ramsbottom piston-rings for steam-hammers and small locomotives. A special wire for making small pinions is also drawn in sizes varying from half an inch down to one-sixteenth of an inch diameter. It is deeply grooved, so as to form from six to twelve ribs or leaves upon it; and when it is cut up into short lengths, the leaves form the teeth of the pinions.

FITZALAN STEEL WORKS.

These works, formerly belonging to Messrs. Marriott and Atkinson, and now to Messrs. Cocker Brothers, extend over an area of four acres in Effingham Road, Attercliffe; and comprise steel-melting furnaces, forge, rolling mills, and file-making machinery. The newest machinery has recently been put down for manufacturing road-van and carriage springs and axles.

In the file department are nine file-cutting machines by Mr. Ambrose Shardlow of Sheffield; a considerable number of files are also cut by hand. A file-grinding machine by Mr. David Ashton of Sheffield, capable of grinding forty dozen blanks per day, consists of a large revolving gritstone carried on a horizontal spindle which has a longitudinal reciprocating traverse imparted to it by means of a cam. The blanks to be ground are placed in a rest, which holds from eighteen to twenty-five at a time; in this they are fed under the stone and withdrawn again, by means of a screw attached to the rest; the screw is actuated by fast and loose pulleys with crossed and open belts.

In the carriage-spring department are forging machines of various kinds, one of which forms at a single blow the two bosses on the ends of the springs. Carriage axles are made from scrap, forged in dies under a steam hammer in a single heat.

A specialty made at these works is a railway-wagon card and ticket fastener, adopted on several of the leading railways, to which over half a million have already been supplied.

WAVERLEY STEEL AND FILE WORKS.

These works, belonging to Messrs. Dickson Brothers and Co., and adjoining the Attercliffe Road Station of the Midland Railway, are of recent erection, and have been specially laid out for the manufacture of crucible cast-steel and of hand-cut files.

The steel works include the pot house in which the fire-clay steel-melting crucibles are made, the mixing room in which the constituents for the steel are weighed off and mixed for melting, the melting furnace itself, and the steel warehouse in which the finished bars are all thoroughly examined. The most interesting process in the manufacture is the "teeming" or casting of the crucible-steel ingots, which takes place three times a day.

The file works consist of forging shops, annealing room for softening the files, cutting shop, hardening shop, scouring room, warehouse, and packing rooms.

BRIGHTSIDE BOILER AND ENGINE WORKS.

These works, situated in Savile Street East, were established in 1860 by the present owner, Mr. G. W. Hawksley, and his late partner, Mr. M. Wild. The manufacture comprises boilers of all kinds with the necessary fittings, feed-water heaters, and apparatus for heating large quantities of water for baths, breweries, &c.

The flanged flued boilers here manufactured have the flues built up in rings of plates of alternate larger and smaller diameter, the difference in diameter being about 4 inches; the ends of the smaller rings are expanded out to fit inside the ends of the larger, which are plain cylindrical rings. The circular seams thus made afford great resistance against collapse, and provide amply for free expansion and contraction; at the same time with the addition of cross tubes they ensure a thorough mixture of the gases passing through the flue. Large numbers of boilers fitted with these flues are working with satisfactory results. The rings forming the flues

are each made from a single plate, bent into a cylindrical form by horizontal plate-rolls of forged steel, which will bend cold steel plates 10 feet wide and 1 inch thick. The ring when rolled envelopes the top roll; and for enabling the ring to be removed from the rolls, the bearings of the top roll are so arranged that one of them can take the weight of the roll, while the other can be screwed back and swung out of the way, so as to release the ring endways. The rivet holes are drilled in position after the plates have been bent to shape. For the circumferential seams there is a three-standard vertical drilling machine by Messrs. Smith and Coventry of Manchester. For the longitudinal seams another vertical drilling machine is employed, having two saddles on a single standard, and two drill spindles to each saddle; the spindles are adjustable so as to drill two rows of holes at suitable pitch. A machine with several motions has a revolving table enabling a circle of 10 feet diameter to be cut by this motion; it has also a revolving head fitted with a massive steel spindle 8 inches diameter, by means of which a very steady cut of 4 feet diameter can be taken. A new boiler shop in course of erection will contain a flanging press capable of flanging at one operation plates 11 feet diameter. It will have four rams, so as to be suitable for lighter work without loss of power; the two centre rams will work concentrically one within the other, whilst the two others will be placed at the sides, thereby affording a considerable range of power, from the single small ram in the centre to the whole four. The first steel boiler made at the starting of the works about thirty years ago was used here until replaced by a larger, and is still working in Sheffield at a pressure of 80 lbs. per square inch. It is of the flued type, fitted with the flanged rings above described; as each ring is made from a single plate, there is no longitudinal line of rivets exposed to the fire.

The feed-water heater manufactured at these works consists of a horizontal or vertical cylindrical casing containing tubes. Exhaust steam from the engine is admitted to the casing, while the feed-water is pumped through the inside of the tubes, and thence direct to the boiler. The heater is divided in two longitudinally, and the water passes first through the tubes in one half, and then returns through

those in the other; the steam travels through the casing in the opposite direction. The same kind of heater is constructed for breweries, dye works, and similar purposes. For a dye works a special filtering apparatus has recently been constructed, which is now satisfactorily filtering 40,000 gallons per hour of impure river water.

SILVER AND ELECTRO-PLATE MANUFACTORY.

These works, belonging to Messrs. William Hutton and Sons, were built in 1885, and occupy a rectangular area of three quarters of an acre, having a frontage 230 feet long to West Street. The workshops, show-rooms, and warehouses are arranged round the outside, and the engine and boiler houses, furnaces, and rolling mills occupy a portion of the yard in the centre. Steam is supplied by two steel Lancashire boilers to two Tangye's 25 horse-power horizontal automatic engines placed side by side, each driving a separate portion of the machinery, while either engine with one of the boilers is sufficient to drive the whole of the machinery if necessary. In the furnaces the metals are mixed and melted in crucibles, and subsequently cast into flat ingots of sterling silver or nickel silver as required. In the rolling mill these ingots are rolled down by special rolls into sheets of suitable thickness.

The works are divided into five departments, each under separate management:—spoon and fork, hollow-ware, cutlery, silver, and electro-plating.

In the spoon and fork department, the sheet metal is first cut into narrow strips and short lengths, which are next thinned down at the ends by being passed through special rolls, then annealed, punched into rough form, and finally stamped into proper shape by steel dies, after which they are ready for finishing and plating. In the machine shop the manufacture of these articles is accelerated and improved by the substitution of reciprocating semi-circular steel dies exerting a great pressure, whereby a better finish is obtained with greatly increased rate of production. Two men with one of these machines are able to produce at the rate of eighty dozen spoons or forks per hour.

In the hollow-ware department are made dinner and tea services, and all kinds of dishes, trays, &c. The sheet metal is stamped into shape and embossed by means of steel dies worked by powerful steam-stamps. Raised borders, handles, spouts &c. are hammered from flat metal; and ornamental castings are made in moulds and afterwards chased. These are then soldered to various articles by means of gas blow-pipes. Spinning and turning are also employed for the production of various shapes.

In the cutlery department, one of the processes is close-plating, or the soldering of sheet silver upon the blades of steel fruit or dessert knives and forks. Pearl and ivory cutting and carving are also carried out in connection with the manufacture of fish, fruit, and dessert knives and forks.

In the sterling silver department, a large number of silversmiths are employed, raising, chasing, embossing, engraving, and otherwise ornamenting all kinds of silver plate and other silver articles. Here are also buffing and burnishing shops, and designing and modelling rooms.

In the electro-plating department, the electric current for the plating vats is supplied by two powerful dynamos; and the articles to be plated are kept in motion by machinery, in order to accelerate the deposit upon them of the silver held in solution. Each article is weighed before being put in and after being taken out of the vat, in order to determine the quantity of silver deposited.

HORSE-HAIR CLOTH WORKS.

In these works, belonging to Messrs. Samuel Laycock and Sons, is conducted every process for the manufacture of horse-hair and hair fabrics. The manufactory, which has been established over a century, is situated in Portobello Place; and from 15 to 20 tons of horse-hair per week are here worked up. The tails and manes are obtained from South America and Siberia, and arrive in a very untidy state, as rough mops of hair, often entangled plentifully with burrs. They have to be carefully washed and combed out, after which the hairs

have to be sorted according to their several lengths. The longest hair is 6 feet, but such a length is rare; usually it does not exceed 5 feet. In weaving horse-hair cloth therefore the weft cannot exceed this length; and as the hair is both hard and elastic, and each single hair is considerably thicker at one end than at the other, the construction of a loom for weaving such material with rapidity and success is attended with peculiar difficulties. The warp is of cotton or flax, and is so buried in the hair that it does not show in the woven fabric. Unless the hair is intended to be woven in its natural colours, it is bleached or dyed before weaving, when an artificially coloured fabric is desired.

A large number of old hand-looms are still employed for weaving the horse-hair cloth. These are each worked by two women, one of whom serves or feeds a single hair at a time to the other, who draws it through the open shed. The hairs have to be laid with their thick and thin ends alternating, in order to keep the thickness of the cloth uniform throughout its width. The cloth is woven from 14 inches to 36 inches wide.

To the rest of the interesting machinery in operation in these works has been added an ingenious loom, the invention of Mr. W. S. Laycock, in which the weaving is done altogether automatically. The bundles of hair are placed in two troughs, one on each side of the loom, all the thick ends being arranged to lie together and nearest to the loom. At each side of the loom, close to the trough of hair, is fixed a selecting instrument, from which a selector descends to the bundle of 15,000 to 20,000 hairs, and selects and withdraws a single hair; this is afterwards taken by the shuttle from the selector, and drawn into the open shed of the warp. The operation is repeated with every alternate movement of the shuttle. Should the selector fail to seize a hair on its first descent, it repeats the attempt a second time, and if necessary a third time, before the shuttle has travelled to and from the other side of the loom. If the selector fails in its third attempt to seize a hair, the weft stop-motion is brought into action, and prevents the shed from changing, and stops the let-off of warp and the take-up motion; and the hair selected by the instrument at the opposite side of the loom is then drawn into the

open shed, thus preventing any imperfection or fault from the above cause in the hair cloth. Not only has the selector to seize the hair and hold it until it is taken by the shuttle, but it must then also let it go at the right instant: not too soon, or else the hair would be dropped; and not too late, or else the hair would be dragged through the gripping fingers of the selector, and these would soon become worn out. The gripping fingers on the shuttle are also similarly arranged to take hold and let go at the right instant. This self-acting loom is employed for weaving hair blind-cloth, hair seating, and other fabrics made with horse-hair, which are now largely used by the principal railways in this country and on the continent.

Curled hair, used for upholstering seats of railway carriages, steamboats, and domestic furniture, is prepared by carding it after washing, and then spinning it into ropes, so as to give it the curl which affords the springiness necessary to make a comfortable cushion.

RAILWAY-CARRIAGE FITTINGS WORKS.

At these works, belonging to Mr. W. S. Laycock, and situated in Victoria Street, novel machinery is employed for the manufacture of blind rollers and other fittings invented by him for railway carriages and steamships, &c. The blind rollers are so contrived that the blind, made usually of horse-hair cloth, will stay in any position intermediate between top and bottom. Within the hollow brass box at one end of the roller is coiled a spiral spring tending to roll the blind up. At the bottom of the blind is a weight just too heavy for the spring to lift: but when the weight is lifted by hand, the blind will roll up. When the weight is unsupported, the blind is prevented from running down by a ratchet and paul in the brass box at the other end of the roller. The ratchet is connected with the roller by a pair of friction discs pressed together by a spring; a slight pull by the hand is sufficient to overcome the friction of the discs, and to draw the blind down. It is then retained in any position by the weight, which is not heavy enough to make

the friction discs slip; while the spring tending to pull the blind up is not strong enough to overcome the weight. The device is simple, and little likely to get out of order.

A double-cone ventilator for railway carriages is constructed of two hollow cones, laid horizontally in the same straight line, base to base, with a space between; the space is surrounded at a short distance by a flat ring, which also covers a short length of the cones. There is thus an annular space between the bases of the cones, and an external annular space between these and the outside ring surrounding them. A short open pipe from the roof of the carriage communicates with the interior of the cones. The horizontal axis of the cones being placed transversely to the direction of motion, the air on striking their surfaces is deflected laterally towards the apex on each side, thereby producing a partial vacuum underneath the flat ring, and thus inducing a suction from the carriage through the short pipe into the interior of the cones. When this pipe is 4 inches diameter, it is found that at a speed of 60 miles an hour a light diaphragm placed across its mouth will support a weight of $2\frac{1}{2}$ ounces.

Among the numerous other articles produced at these works are lubricators for axle journals, spring seats, window lifts, and draught excluders. The machinery employed in the manufacture is driven by a gas engine, and the electric lighting apparatus by another of a different kind.

ROYAL CUTLERY AND SILVER-PLATE WORKS.

These works, belonging to Messrs. Mappin and Webb, are centrally situated in Norfolk Street, and include an extensive range of melting furnaces, rolling mills, hammer shops, steam-stamp shops, grinding wheels, forging hearths, and silversmiths', cutlers', engraving, chasing, and fluting shops; also cutting out, buffing, finishing, spinning, and turning machinery shops. The whole are systematically arranged, so that the production of every article can be traced from the first stage to the last. In the plating room are

some of the largest cast-iron vats ever constructed, containing silver and gold solutions; and the process of electrical deposition, with its numerous appliances and intricate machinery, can here be seen throughout its whole extent.

SHEFFIELD TESTING WORKS.

These works, situated in Blonk Street, were established by Mr. Thomas Nash for the testing of steel, iron, and all other metals, and all kinds of springs. They are well provided with machinery for preparing specimens to be tested. The machines are driven by a horizontal engine, to which steam is supplied from a locomotive boiler having a safe working pressure of 200 lbs. per square inch. The large testing machine is actuated by a three-throw pump, made by Messrs. Nasmyth Wilson and Co. of Patricroft. A special feature in connection with testing the specimens is an annealing furnace, in which they can be annealed without contact either with the flames or with the products of combustion.

CLYDE STEEL AND IRON WORKS.

At these works, the property of Messrs. Samuel Osborn and Co., the manufacture of Mushet's self-hardening steel has been carried on for many years. This special steel is made in crucibles in the usual way, and is chiefly employed for engineers' cutting tools. It possesses the property of becoming hard on simply being allowed to cool gradually in the air after forging; this is a great advantage in the production of milling cutters and many other tools, because the shape of the tool is less liable to become distorted as it so often does when made of ordinary steel and hardened in the usual way by sudden cooling. With tools made from Mushet's steel the cutting speed may be increased 25 to 50 per cent. beyond the ordinary speed without the cutting edge being injured by heat; but more care must be taken in dealing with the work, as the steel is harder than

ordinary steel. Its specific gravity is 9 per cent. greater than that of ordinary steel, and it has a very close grain; it has not yet been welded, even by electricity. Mushet's titanic steel is also made here, including one sort that is weldable. It is specially adapted for mining tools and rock drills, and is not self-hardening.

The more ordinary branches of manufacture include various kinds of steel, from "extra best cast-steel" suitable for cutting tools, down to the cheaper qualities in which a durable cutting edge is not required. For railway springs, which are a leading branch of manufacture, the steel is rolled into bars and cut to the required lengths, the ends are ground, holes are drilled when necessary, and the leaves are cambered and built up. Steel shafting is produced by a combined action of rolling and reeling. The shaft is made hot and rolled between a pair of face rolls, which have their faces in vertical planes but not quite parallel, and are forced together by a screw actuated by a hand wheel. As they revolve in opposite directions, the shaft which is being rolled is spun round on its own axis at the same time that it is fed forwards, and it passes between the face rolls near to their circumferences.

There are three other iron and steel works in Sheffield belonging to the firm. One is a foundry in Rutland Road, for the production of steel castings up to 15 tons or more; another is a crucible-steel foundry in Bridge Street for special work. Here are made portable ramps for re-railing rolling stock, railway wheels, crank axles, buffer cases, horn blocks, crossings, propeller blades, paddle-wheel centres, steam-hammer tups, hydraulic cylinders, spurwheels and pinions, and various mining and engineering work. Machine moulding from the smallest to the largest gearing in use is done by four of Whittaker's moulding machines. At the Brookhill Works are manufactured high-class engineers' files, saws, machine knives, hammers, and similar articles. The four works together employ usually between nine hundred and a thousand hands.

CUTLERY MANUFACTORY.

This establishment, belonging to Messrs. Joseph Rodgers and Sons, occupies the whole block of buildings skirted by Norfolk Street, Milk Street, Sycamore Street, and Flat Street. The Rodgers family have been cutlers for at least two centuries. In 1730 the firm, consisting then of Maurice and Joseph Rodgers, removed from Hollis Croft to Sycamore Street, where, as the business increased, the premises were gradually extended and rebuilt, until in 1869 they occupied the whole of the present block with frontage in Norfolk Street. In 1764 they received from the Cutlers' Company of Hallamshire their trade mark, a Maltese cross and star. In 1800 they added to their original trade of penknife cutlers the manufacture of razors and table knives, and a few years later commenced that of scissors. About 1821 they were made by special appointment cutlers to the Royal family, which distinction they continue to enjoy. They now employ about 2,000 workmen.

In the show-room is a knife containing between 1,800 and 1,900 blades and instruments, all quite distinct and no two alike. Here is also shown the celebrated Norfolk knife, the blades of which are etched with portraits and views; the handle is of carved pearl, and represents hunting scenes.

DANNEMORA STEEL WORKS.

These works were acquired in 1869 by the present proprietors, Messrs. Seebohm * and Dieckstahl, and by extensive alterations were transformed into crucible-steel works. The finest qualities of crucible cast-steel are made from bar steel which has been converted from Swedish wrought-iron manufactured from the Dannemora ore containing manganese; this natural manganese in the ore is of great value, as it will not do to add the manganese in the form of spiegel-eisen or ferro-manganese to iron manufactured from an ore not containing manganese.

* Iron and Steel Institute Journal, 1884 II, page 372. "On the Manufacture of Crucible Cast-Steel;" by Henry Seebohm.

The wrought-iron having been rolled into bars about 3 inches wide and 5-8ths inch thick and 12 feet long, these are first converted into blister steel, in furnaces having the large conical stacks which form a conspicuous feature of works making crucible steel. The iron bars are placed in rectangular troughs, about 3 or 4 feet square and 12 feet long, called converting pots, which are constructed of refractory material. The pots are built into the bottom of the converting furnace, and a brick arch is turned over them with suitable flues; the fire is underneath the pots, and the whole is surmounted by the conical chimney. Each converting furnace holds altogether from 15 to 35 tons of iron in two pots; it is generally considered that better steel is produced from the smaller pots. A bed of hardwood charcoal is laid in the bottom of each pot; and above this are placed alternate layers of iron bars and charcoal, until the pot is full; it is then closed with a thick cover of wheel-swarf, the silicious mud which accumulates at the troughs of the Sheffield grinding wheels; this substance resists long exposure to great heat, and renders the top of the pot practically air-tight. The fire is so regulated as to bring the mass of iron and charcoal to nearly a white heat, which is gradually reached in the course of six to nine days, according to the temper or percentage of carbon required. The temperature is then let down gradually, the furnace requiring eight or nine days to cool down before the bars can be drawn out of the pots. When the cover is removed from the pot, a certain portion of the carbon has penetrated into the substance of the bars and entered into combination with the iron, forming blister steel. It is necessary to prevent all entrance of air into the pots during the conversion or "cementation," otherwise the charcoal would be burnt and the iron might be oxidised. If the heat is not properly managed, the pots may crack during the process. The pots last for using from twenty to forty times. If the heat is raised too high, the bars become glazed by the melting of their surface. The proportion of carbon contained in the steel varies from $\frac{1}{2}$ to $1\frac{1}{2}$ per cent. The blister steel containing $\frac{1}{2}$ per cent. is known as a "spring heat," and that containing $1\frac{1}{2}$ per cent. as a "melting heat." The carbon is taken up by the surface of the iron bars, and penetrates

further through their thickness according to the length of time the heat is maintained. In a "spring heat" the interior of the bar remains iron, although the crystals have lost their brilliancy. In a "country heat," containing $\frac{5}{8}$ per cent. of carbon, the crystals of steel on the edges have become more distinct. In a "single-shear heat," containing $\frac{3}{4}$ per cent. of carbon, there is more steel on the outside and less iron in the centre; until in a "double-shear heat," containing 1 per cent. of carbon, the steel and iron are about equal. A "steel-through heat," containing $1\frac{1}{4}$ per cent. of carbon, and a "melting heat," containing $1\frac{1}{2}$ per cent., are both of them all steel; in the former the crystals of steel are small, and in the latter a rather longer time in the furnace has rendered them large.

From the bars of blister steel may be made either shear steel or cast steel. Shear steel consists of bars of blister steel welded together and rolled or drawn down under a hammer. As the blister-steel bars have in neither case undergone conversion long enough to make them steel all through, the shear steel, whether single-shear or double-shear, is really made up of a mass of iron and steel mechanically mixed. The double-shear steel is twice welded: after the blister-steel bars have been welded together and drawn down to suitable size, they are then welded together again and drawn down a second time. The object of making shear steel is to obtain as far as possible the valuable qualities of both iron and steel in one material: namely the ductility or toughness of iron combined with the hardness of steel.

Cast steel is made from blister steel by melting it in clay crucibles, called "pots." The temper, that is the hardness or softness of the cast steel, depends upon the percentage of carbon in the blister steel. The quality of the steel depends upon the character of the Swedish or other iron from which it is converted. The pots are placed in a furnace beneath the floor, and the furnace is fired by coke piled around them. The bars of blister steel are broken up into small pieces, which are charged through a funnel into the pots while in the furnace; the process of conversion having changed the character of the metal, the bars are easily broken for the purpose by the hammer. When the melting pot has been

charged, the lid is put on, and the furnace or melting hole is filled up with coke. The degree of heat has to be properly adjusted, as well as the time that the crucible is allowed to remain in the furnace; this part of the process therefore requires the exercise of care and judgment. After the steel has become liquid, it has to be boiled in the pot for nearly half an hour, which is called "killing," until it is "dead-melted"; the higher the quality of the steel, the more killing does it require. It is in this part of the process of melting crucible cast-steel that its advantage as compared with the Bessemer or Siemens process is considered chiefly to lie. The pots are used three times, after which they are so reduced in thickness as to be useless. The first melting, when the heat of the furnace has to be got up again after having been let down, occupies four or even five hours; for the second and third meltings, when the furnace is already hot, the time is reduced to two hours and a half. The charges are diminished as the pots wear: the first is generally from 50 to 70 lbs., and the third from 38 to 40 lbs., according to the size of the crucibles. When ready the pots are lifted out of the melting holes by tongs; care has to be taken not to crush the pot, while yet gripping it tight enough to prevent it from slipping. The cover having been removed, the metal is freed from slag by skimming it with a bar of iron having a lump of slag on its end, around which the slag floating on the molten metal solidifies. The liquid steel is then poured or "teemed" into the ingot moulds, which are made in halves and held together by iron bands.

This is the identical process of making crucible or cast steel which was introduced into Sheffield a century and a half ago by Benjamin Huntsman, and has continued unaltered to the present day. As the Swedish iron is procured of uniform quality, containing just the ingredients required and practically free from impurities, there is the less need of continuous analysis; and the eye becomes so well trained by long practice, that it is said an experienced steelmaker can discriminate by the fracture the proportion of carbon to the minute extent of only one-tenth of one per cent., and even less.

ÆTNA EDGE-TOOL WORKS.

These extensive works, belonging to Messrs. Spear and Jackson, are situated in Savile Street East, and have been established over a century for the manufacture of saws, files, and tools of almost all kinds. They are furnished with all modern facilities for the perfection of manufacture of these various productions, all of which are made and manipulated on the premises from the crude material up to the finished article. The firm make their own steel by the cementation and crucible process, rolling it into bars, rods, and sheets, as required.

One of the chief branches of the work here carried on is saw making. Rolled sheets of steel are taken from the mill and pared to shape in shearing presses. The blanks then have the teeth punched out in other presses; after which they are hardened, hammered, and straightened ready for grinding. The grinding is done between two stones placed one above the other, whereby both sides of the saw are ground simultaneously. The axes of the two stones are not exactly parallel, so that the grinding surfaces are also at a slight angle. By this means the back of the saw is made somewhat thinner than the toothed edge, thereby enabling the saw to clear itself in the cut. The surfaces are finished by means of wooden rollers covered with leather, on which emery powder is fed by hand. The saw is then sharpened and set by hand, and lastly fitted with handles.

In the department for making garden and field tools, steel shovels forged solid are a special article of manufacture. These are first hammered out of a solid block by a machine hammer, after which they are pared to shape by a shearing press. The piece, which is still flat, is then heated and dished to the required shape under a drop hammer. The strap, which is forged out solid with the rest, is then riveted upon the wooden handle, and rounded to fit it by means of half rolls; after which the implement is completed by finishing portions of it on a leather band with emery. Digging and hay forks are forged solid, and the straps for attachment to the wooden handle are welded on. In the wood department, where shafts and handles are prepared for the different tools, the wood is

steamed and bent into the various curved shapes required by means of a machine with dies, into which the wood is pressed by a cam action.

The steelmaking department comprises the usual crucibles and other appliances; and the sheet mill contains rolls to produce steel sheets up to five feet square. There is a large hammer forge, and a steam press for shaping plough boards and articles of a similar kind. A large file-making department produces files of all kinds for engineers, saw-mills, &c. Reaper and mower and hay and sugar-cane knives, scythes, axes, chisels, plane irons, picks and mattocks, matchets, hoes, tools for paper mills and tanneries, mining tools, and many kinds of engineers' tools are also made.

BELLEFIELD SAND-BLAST WORKS.

In these works, situated in Bellefield Lane, Tilghman's Sand-Blast process has been carried on for nine years past. A jet of sand, propelled at a high velocity by a steam or air blast, is employed for cutting and producing ornamental carving on stone and other materials, grinding and ornamenting the surface of glass, sharpening and scouring files, cleaning castings and other metallic surfaces, and recently for artistic lithography. The hardest steel, chilled cast-iron, or other metal can thus be cut by a stream of quartz sand. For sharpening and scouring files, a stream of fine sand and water in the state of fluid mud, directed at a certain angle with the face of the file, is driven with great velocity by jets of steam against the backs of the teeth, and grinds away the burr or curl produced by the chisel, giving to the teeth keen and well-supported edges. Files so treated are found to cut faster, work more freely, and wear longer than the ordinary kind; and the process is now in operation at several of the largest file manufactories. When applied to the cleaning of brass, iron, or steel castings, the process entirely removes the sand, and the hard skin or scale which is found so destructive to the edges of files and cutting tools. When applied to lithography, the process consists in blasting out minute particles of the prepared stone, on which an

outline has already been sketched, by means of a fine stream of sand propelled by an air blast from the nozzle of an instrument guided by hand. Sharp lines and tints of every degree of softness can be produced by varying the position of the instrument, the air pressure, and the quantity of sand escaping. The various applications of the sand blast are shown in operation at the works, and illustrate the progress made since the paper on this subject was read to the Institution seventeen years ago (Proceedings 1873, page 260).

ELECTRO WORKS, HOWARD STREET.

These works, carried on under the name of the original founders Messrs. Walker and Hall, are situated in Howard Street, and were established about half a century ago by Mr. George Walker, immediately after the discovery of the process of electro-plating by Mr. Wright, a Sheffield surgeon. Starting with a few hands they now employ over 800 in the manufacture of all classes of goods from the nickel-silver base. The following processes are seen in operation:—casting of nickel-silver, stamping into shape, spinning of flat sheets into various forms, silversmiths' work, engraving, chasing, forging of steel blades, carving of ivory and pearl, mounting of steel and silver cutlery, sand buffing, burnishing, manufacture of spoons and forks, and electro-plating.

NUNNERY COLLIERY.

This colliery comprises four drawing pits, of which the two principal, situated about 1½ miles from the Victoria Railway Station, Sheffield, raise coal from the Silkstone and Parkgate seams. Both of them are fitted with large winding engines, made by Messrs. Davy Brothers, Sheffield, which have now been at work for twenty-two years. The Parkgate engine winds from two levels, by means of two diameters of drum. Both engines are under the same roof, and are fitted with steam and foot brakes. The Silkstone workings are now at a

great distance from the shaft; and the underground haulage is dealt with by a main and tail rope along a level over 2,000 yards in length; and from the further end of this level to the face by a main rope down a plane about 1,500 yards long, dipping on the average 1 in 10.

The engines working this system of ropes are at the surface. The main-and-tail-rope engine is a double direct-acting engine made by the Yorkshire Engine Co.; it was erected about September 1888. The main-rope engine is a double direct-acting condensing engine, and the drum is fitted with a special form of friction-clutch.

A new fan engine, made by Messrs. Walker Brothers, Wigan, has recently been erected. It is a compound engine, working a driving wheel of 16 feet diameter, which is geared by fourteen $1\frac{1}{4}$ inch ropes to an 8 ft. wheel on the fan shaft.

Seven steel boilers, made by Messrs. Hawksley Wild and Co., 30 feet long and 7 feet diameter, were erected in 1884, and are fitted with Proctor's mechanical stokers, which enable a very inferior class of coal to be used for firing. There is also fitted to this range of boilers a Lowcock's economiser, through which the water is sent into the boilers at a temperature of from 280° to 310° Fahr.

The pumping at the colliery is very heavy, and a large Cornish beam engine with 86-inch cylinder and 10 feet stroke is kept constantly at work. To each end of the boiler-plate beam are attached the pump spears, namely 18-inch and 16-inch sets to the Silkstone seam at a depth of 220 yards, pumping up 110 yards to the Parkgate seam, to which there are two 26-inch sets at a depth of 110 yards, these two being equal to 2,000 gallons per minute.

There are three duplicate horizontal direct-acting compound pumping engines underground, made by Messrs. Hathorn Davey and Co., Leeds; they are fitted with 15-inch ram, and are each capable of pumping 1,000 gallons per minute. One pumps from the Silkstone to the Parkgate seam, and the other two from the Parkgate to the surface. A Priestman's petroleum engine has just been set to work in the Silkstone workings, geared to a Warner's three-throw pump, for dealing with the water in the dip workings.

The dry separation plant on the surface is very complete. It consists essentially of three sets of jigging screens, which separate the coal into three sizes; and four large travelling belts, on which the dirt is picked out from the coal. By this means the coal is mechanically divided into twelve different sorts, and the plant is capable of dealing with 250 tons of coal per hour.

At the Woodthorpe pit a Cockson fan is at work, which is driven direct by a Willans and Robinson engine making 280 revolutions per minute.

TINSLEY STEEL, IRON, AND WIRE WORKS.

These works, belonging to Messrs. William Cooke and Co., are situated at Tinsley, 2½ miles from Sheffield. They were established in 1866, and comprise two blast-furnaces, one in and one out of blast, puddling furnaces, steam hammers for shingling, puddled-bar rolling-mills, and three merchant-mills, 14 inch, 10 inch, and 9 inch. There is also a steel-wire rod-mill, adapted for rolling rods in lengths suitable for telegraph wire; and two wire-drawing mills, engaged principally in drawing wire for ropes of all kinds; also complete appliances for galvanizing. For the manufacture of wire ropes, plant of the most modern description was erected in 1887, which is kept fully employed.

YORKSHIRE ENGINE WORKS.

These works were built in 1866 for the manufacture of locomotive engines upon a large scale. Circumstances however having since directed part of that trade into other channels, they are now mostly employed upon general engineering work, including all classes of stationary engines, torpedo engines, and boilers for locomotive, stationary, and marine engines. Light locomotives of different kinds, weighing only 3 tons, are now in course of construction for railways of 18 inches gauge, as well as the heaviest class of Fairlie engine

having twelve wheels and weighing 86 tons. Other locomotives of this class are being built for 3 ft. 6 ins. gauge; also four-wheel and six-wheel engines for collieries and contractors, as well as a locomotive to be driven by electricity. Special machinery has been put down for finishing marine forgings and castings of the heaviest description, which have been supplied for war ships and American liners. A quantity of work for the Admiralty is now in hand; also air-compressing machinery, colliery plant, and coal-cutting machines. The works comprise a large machine-shop, fitting shop, and boiler shop; a foundry having a 30-ton overhead travelling crane, Root's blower, and every facility for producing castings up to 50 tons. The forge comprises four hammers, and large smithy. There is also a capacious erecting shop, well provided with steam-power, overhead cranes, &c. The works cover ten acres, and employ between 500 and 600 men. They are connected with the Manchester Sheffield and Lincolnshire and the Midland Railway, the nearest station on the former being Meadow Hall and on the latter Wincobank.

ALDWARKE MAIN COLLIERY.

At this colliery, belonging to Messrs. John Brown and Co., there are a pair of horizontal winding engines with cylinders 36 ins. diameter and 6 ft. stroke, raising with flat ropes 150 tons of coal per hour or 1,500 tons per day from a seam 5½ feet thick at 430 yards depth; the cages are double-decked, each cage taking six tubs; the time occupied in the lift is 47 seconds, and in the banking of the six tubs 5 seconds. The oscillating screens and picking bands are adapted for sorting and cleaning 250 tons per hour. Also another pair of horizontal winding engines with cylinders 22 ins. diameter and 4½ ft. stroke, raising 100 tons per hour from a seam 5 feet thick at 230 yards depth; and oscillating screens and picking bands for sorting and cleaning 150 tons per hour. Three pairs of horizontal hauling engines, with cylinders 14 ins. diameter by 2½ ft. stroke, and 22 ins. diameter by 4 ft. stroke, and 24 ins. diameter by 4 ft. stroke, are fixed at surface, the ropes being carried down the shafts in pipes. Two

Schiele fans 14 ft. diameter are driven by belting from engines with cylinders 24 ins. diameter by 3 ft. stroke, and 22 ins. diameter by 3 ft. stroke; and each fan produces a current of 200,000 cubic feet of air per minute. Slack grinding, washing, and coking in beehive ovens are carried on to the extent of 1,200 tons of coke per week.

A miners' safety-lamp testing apparatus is employed, similar to that used by the Royal Commission on accidents in mines; the ignited lamp to be tested is placed in a chamber with a glass side and loose lid, and an explosive current of gas and air mixed in known proportions is passed through the chamber at a measured velocity.

Goliath Flange Rail, 100 lbs. per yard, with Steel Base-plate, 1889.

Fig. 1. *Plan.*

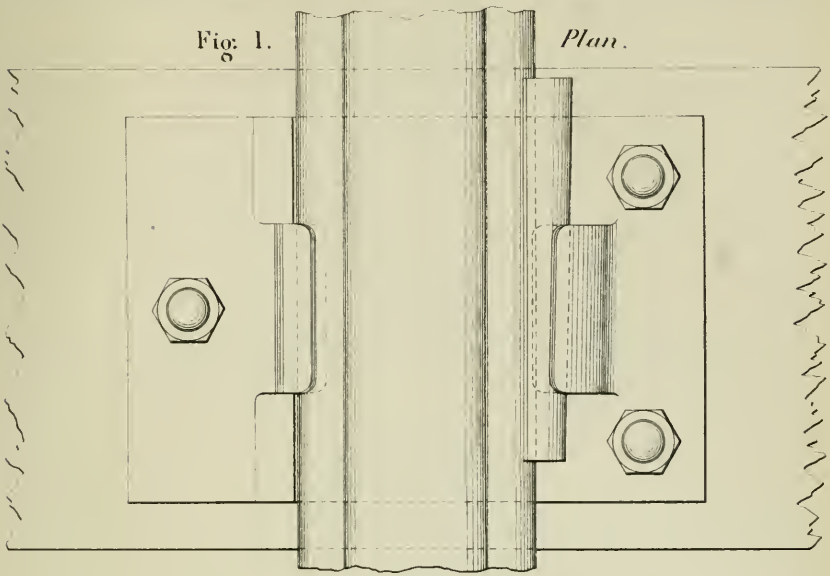
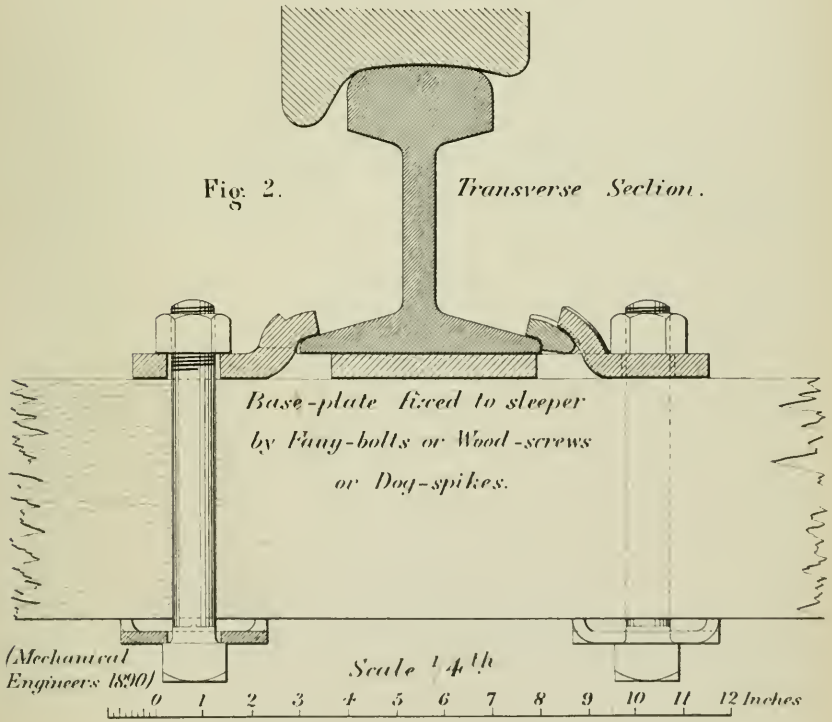


Fig. 2. *Transverse Section.*



(Mechanical Engineers 1890)

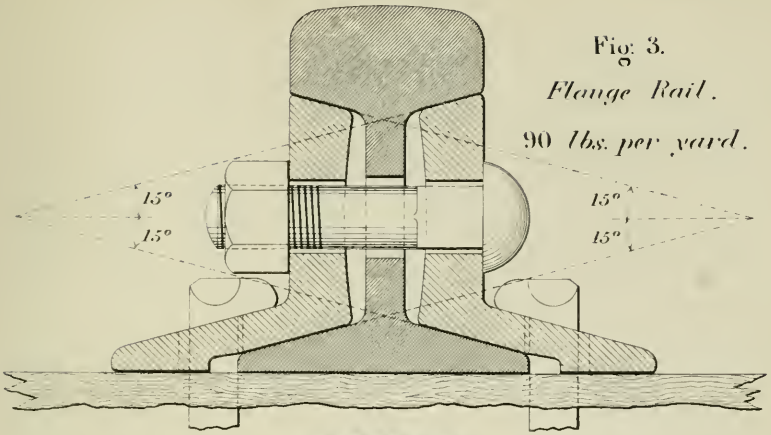


Fig. 3.
Flange Rail.
90 *lbs. per yard.*

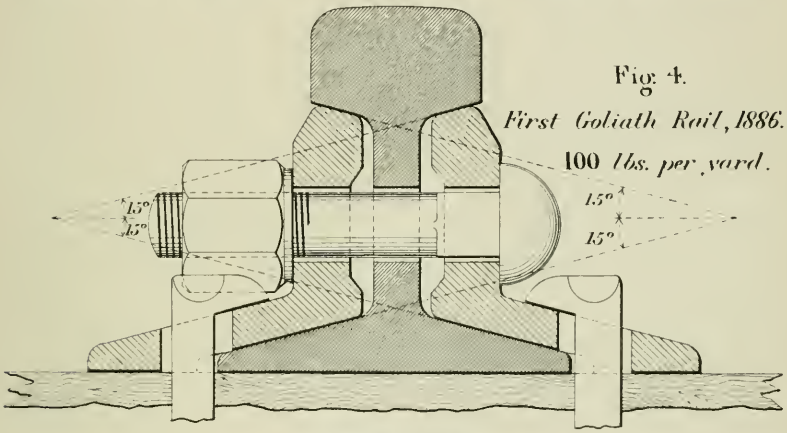


Fig. 4.
First Goliath Rail, 1886.
100 *lbs. per yard.*

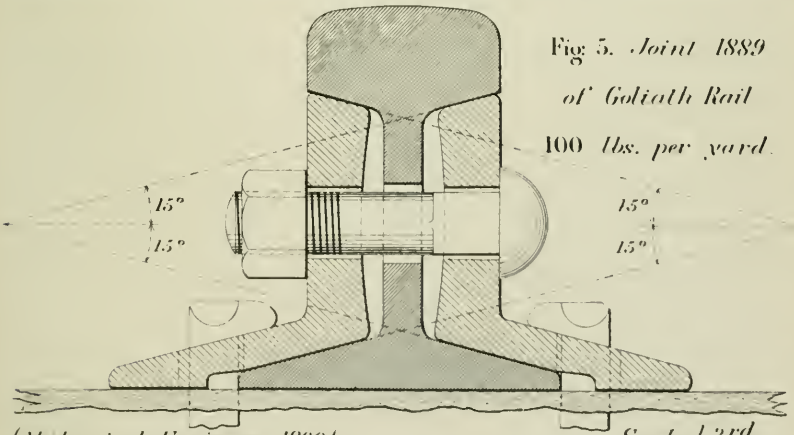


Fig. 5. *Joint 1889 of Goliath Rail*
100 *lbs. per yard.*

(Mechanical Engineers 1890)

Scale 1/3rd

0 1 2 3 4 5 6 7 8 Inches

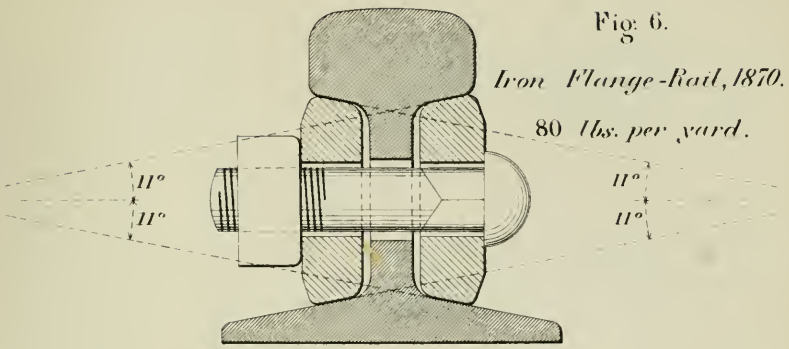


Fig. 6.

Iron Flange-Rail, 1870.

80 *lbs. per yard.*

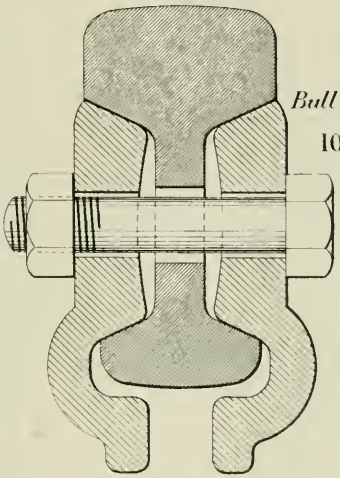


Fig. 7.

Bull-headed Rail, 1889.

100 *lbs. per yard.*

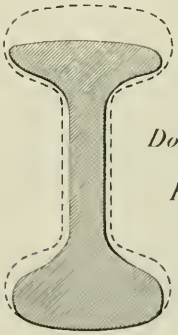


Fig. 8.

Double-headed Rail.

Furness Railway.

75 *lbs. per yard.*

(Mechanical Engineers 1890)

Scale $\frac{1}{3}$ *rd*

0 1 2 3 4 5 6 7 8 *Inches*

Fig. 1. *Sinking Pump.*

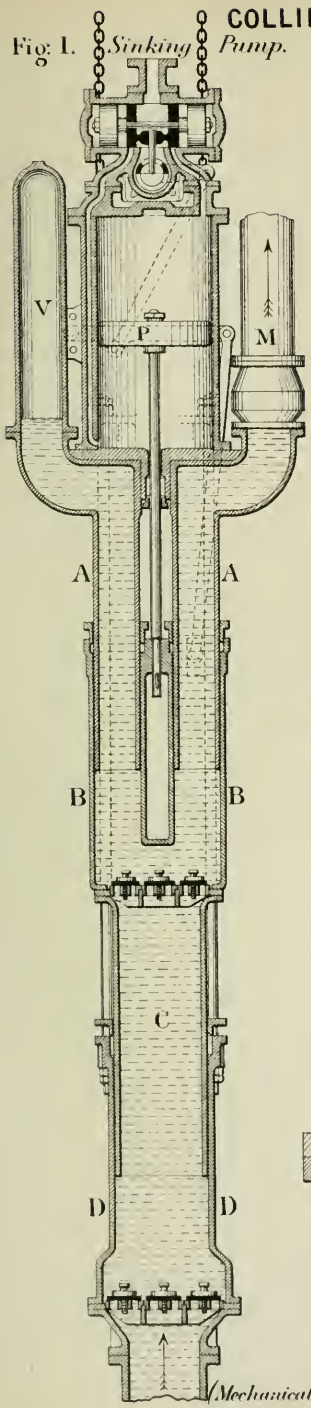


Fig. 2. *Coupling for broken Pipe.*

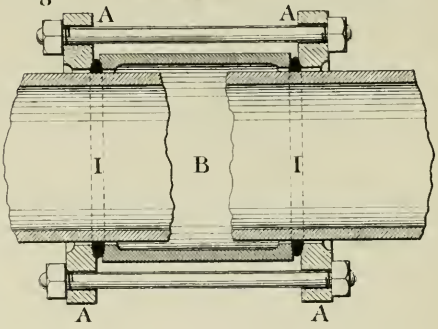


Fig. 3. *Pipe Joint.*

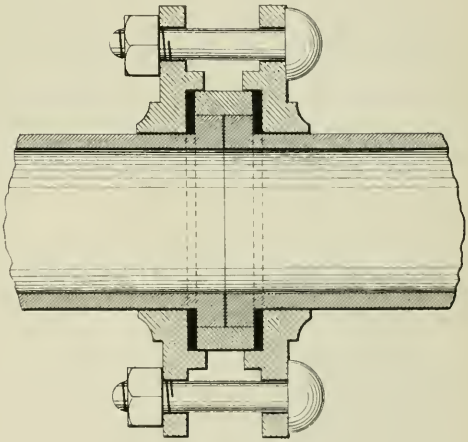
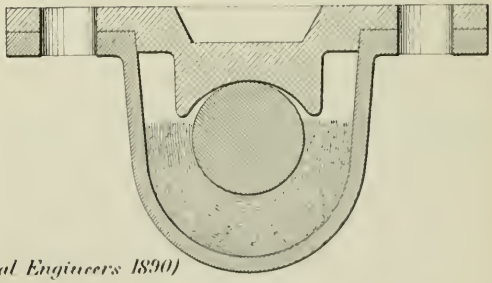


Fig. 4. *Lubrication of Tub Axles.*



(Mechanical Engineers 1890)

Fig. 5.
Winding with Endless Rope.

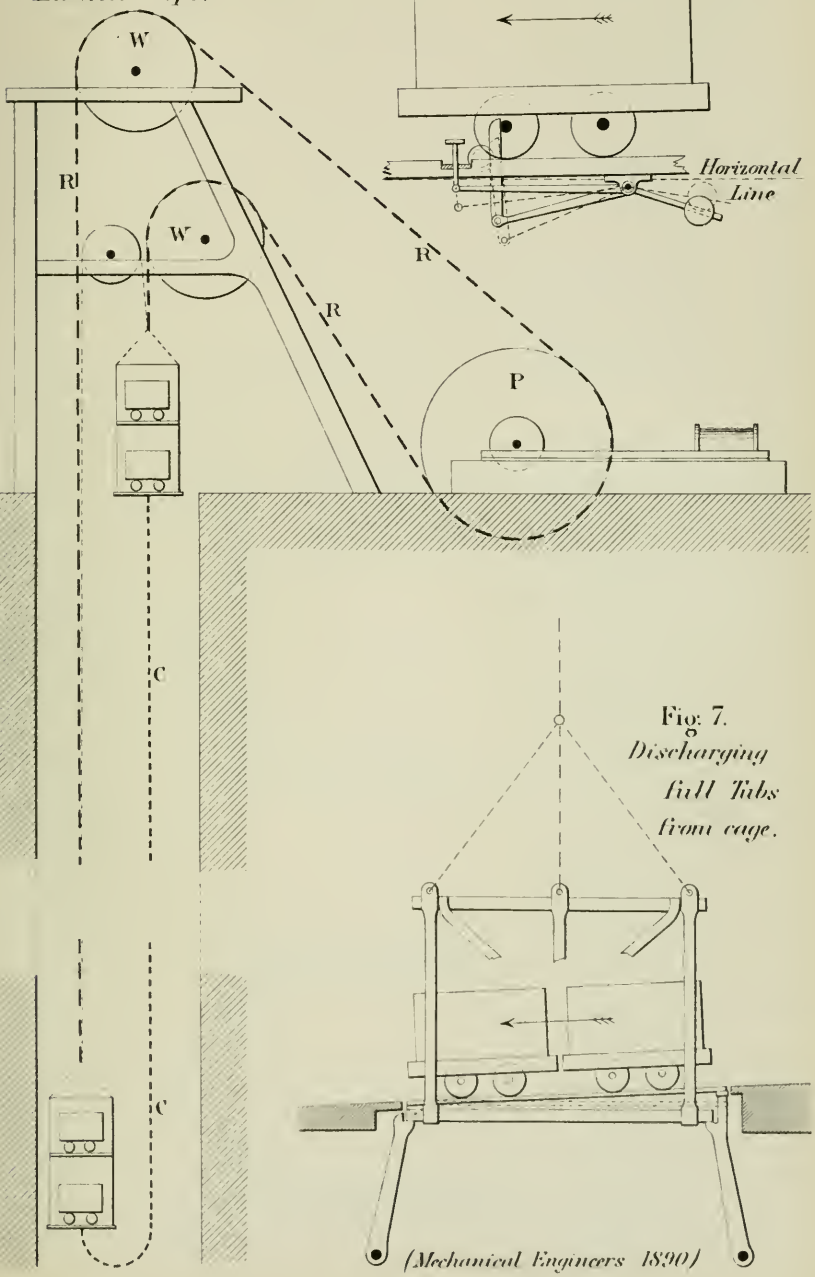


Fig. 6. *Holding back empty Tubs.*

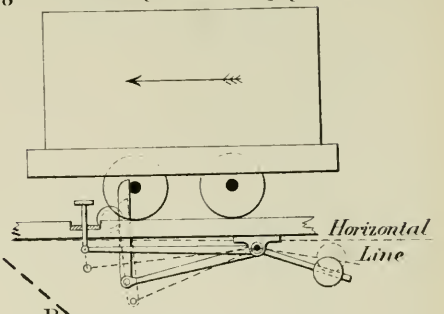


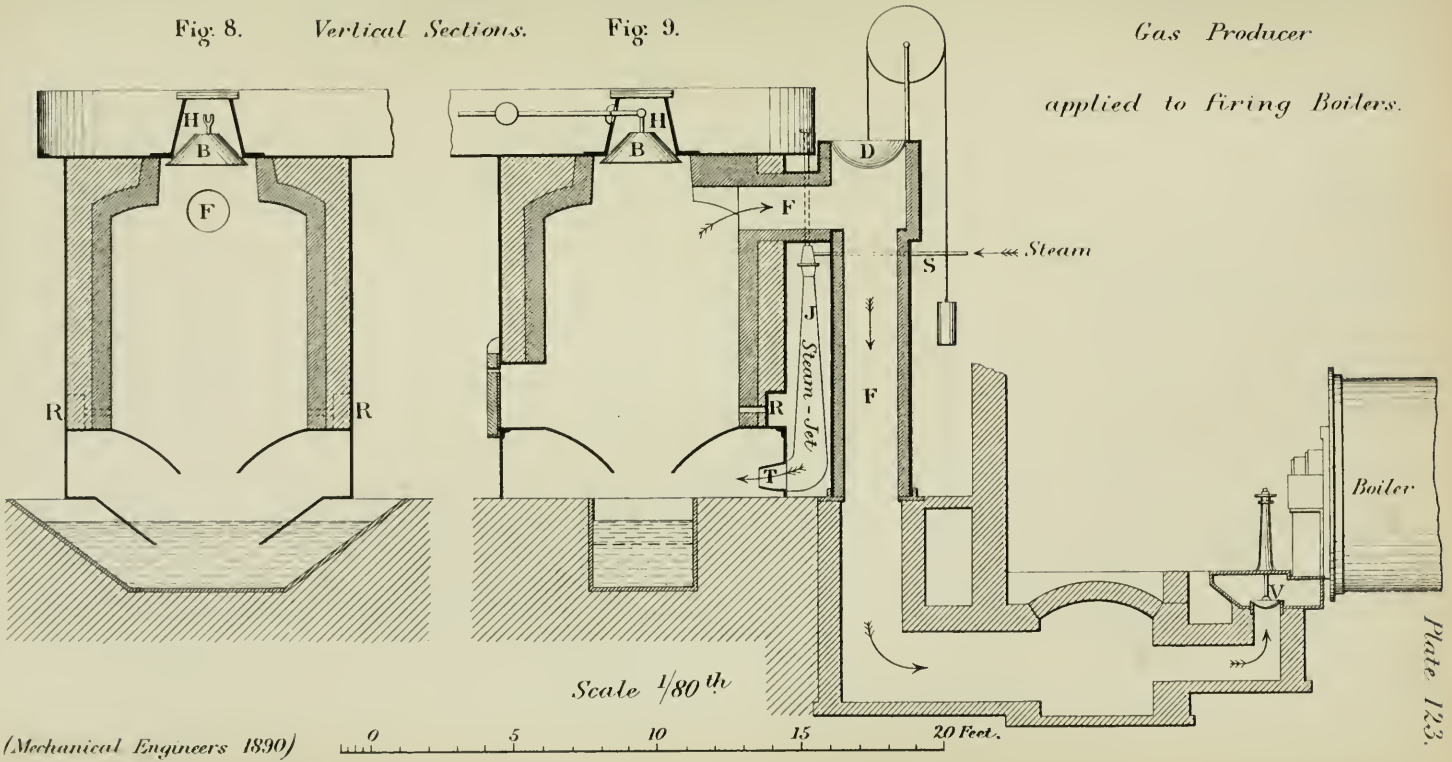
Fig. 7.
Discharging full Tubs from cage.

(Mechanical Engineers 1890)

Fig. 8. *Vertical Sections.* Fig. 9.

Gas Producer

applied to Firing Boilers.



(Mechanical Engineers 1890)

Plate 123.

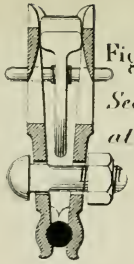


Fig. 10. *Section at* X X.

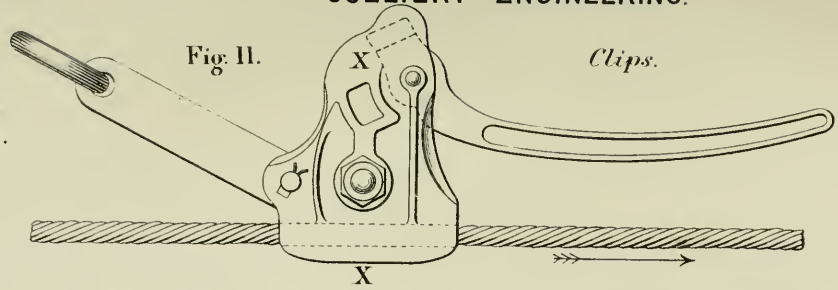


Fig. 11. *Clips.*

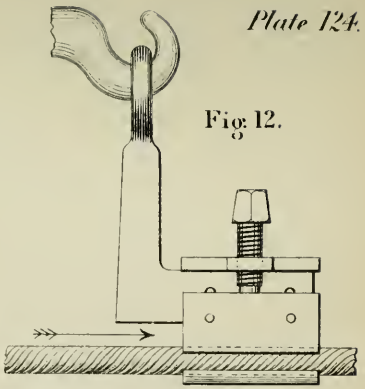


Fig. 12.

Steel Sleepers.

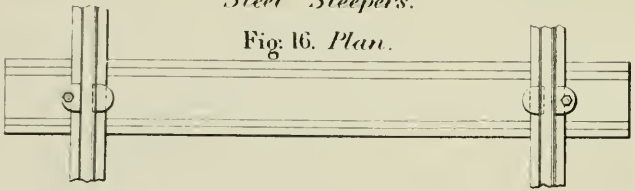


Fig. 16. *Plan.*

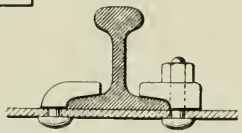


Fig. 18. *Attachment of Rail.*

Fig. 17. *Elevation.*

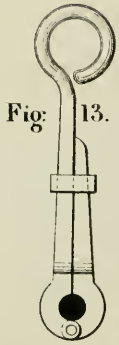


Fig. 13.

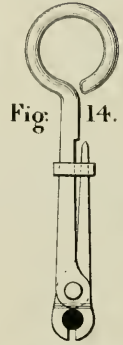


Fig. 14.

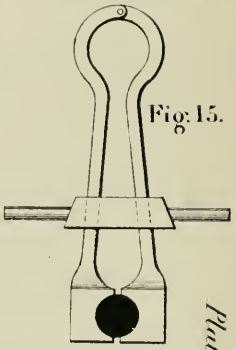
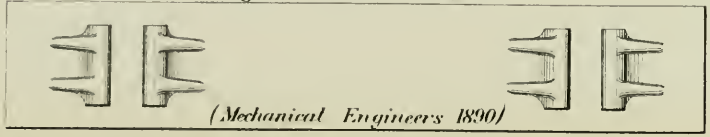


Fig. 15.

Fig. 19. *Plan of Fig. 20.*



(Mechanical Engineers 1890)

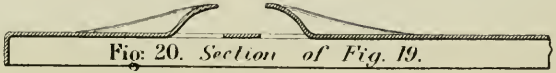


Fig. 20. *Section of Fig. 19.*

Plate 124.

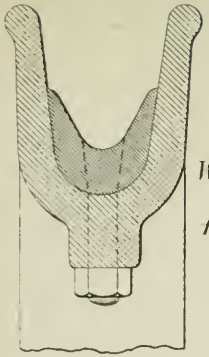


Fig. 21.
Wheel with false Trod.

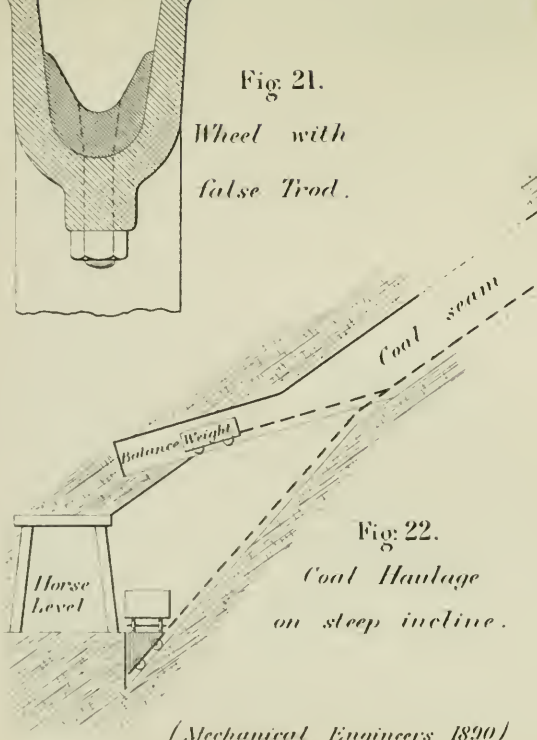


Fig. 22.
Coal Haulage on steep incline.

(Mechanical Engineers 1890)

Fig. 23.
Emptying of Cage at pit bottom.

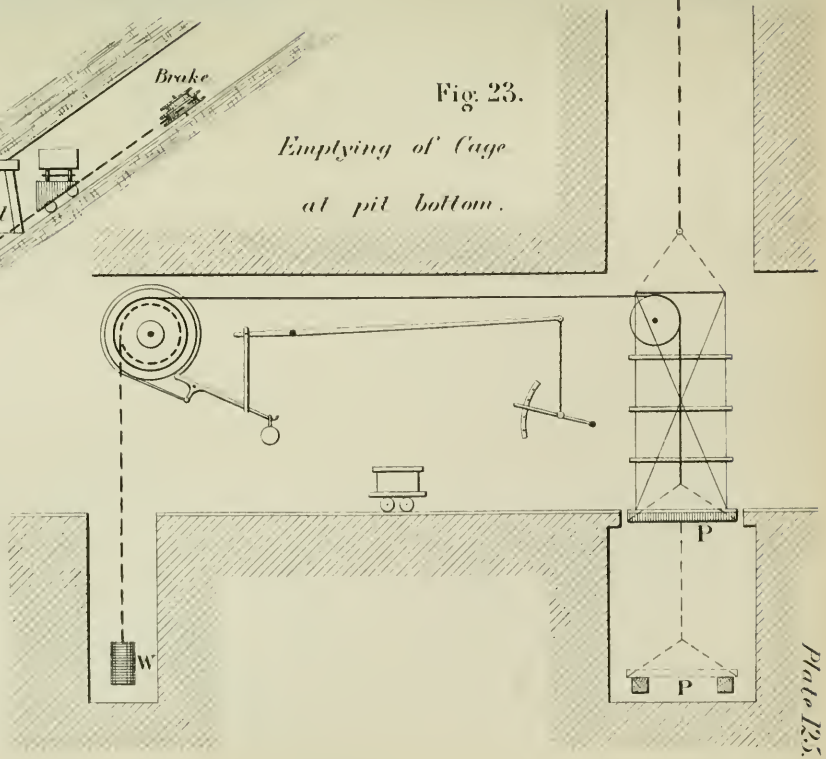


Plate 125.

Tubular Steel Prop and Beam.

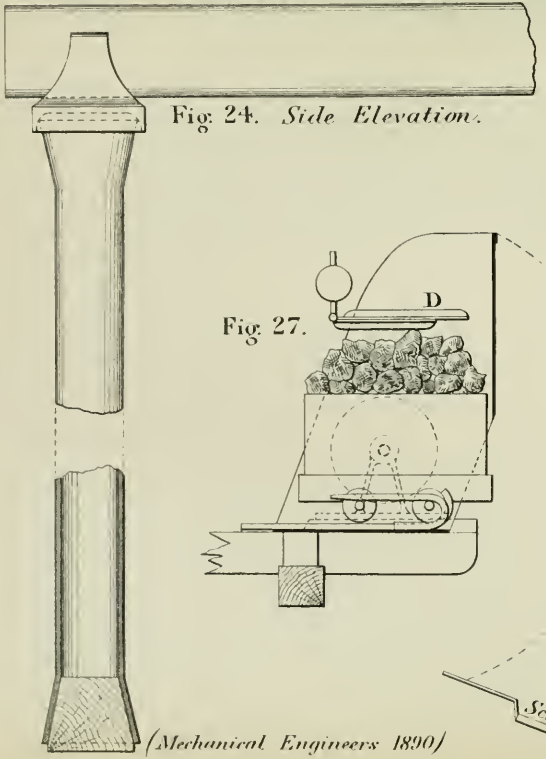


Fig. 24. *Side Elevation.*

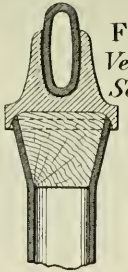


Fig. 25. *Vertical Section.*

Fig. 26. *End Tippler.*

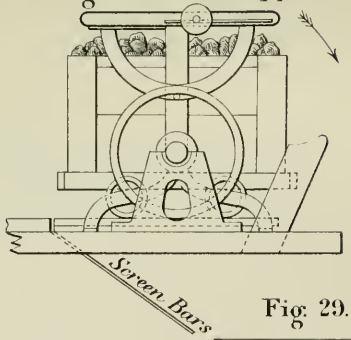


Fig. 27.

End Tippler.

Fig. 28.

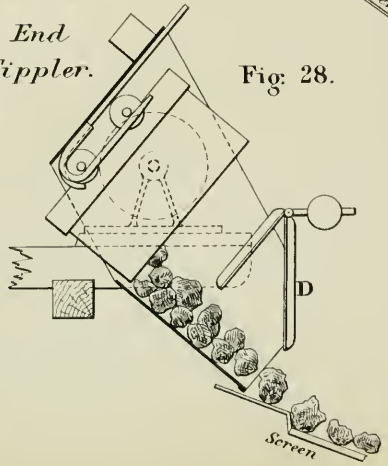
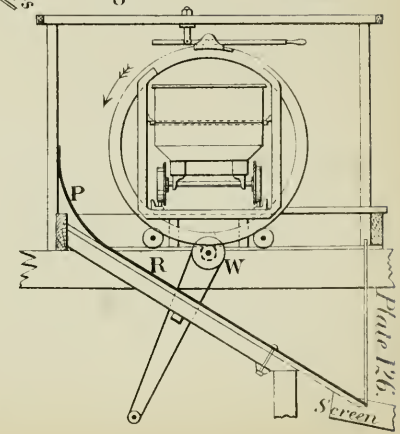


Fig. 29. *Side Tippler.*



(Mechanical Engineers 1890)

Plate 126.

Fig. 30.

Fig. 31. *Steel Girders.*

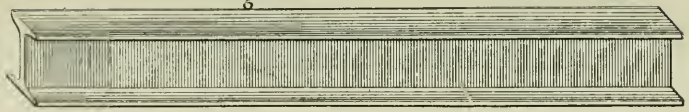


Fig. 32.

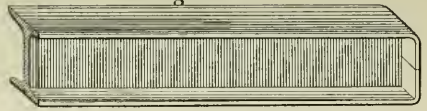


Fig. 33.

Screening by Travelling Belt. Fig. 34. *Plan.*

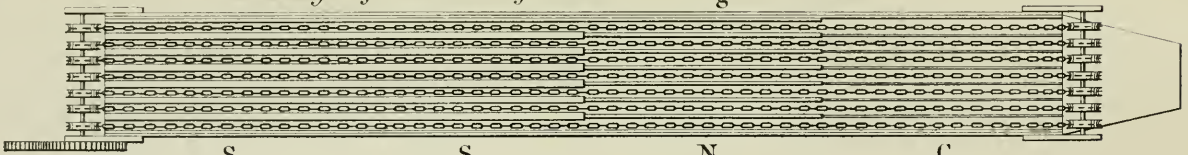


Fig. 35. *Side Elevation.*

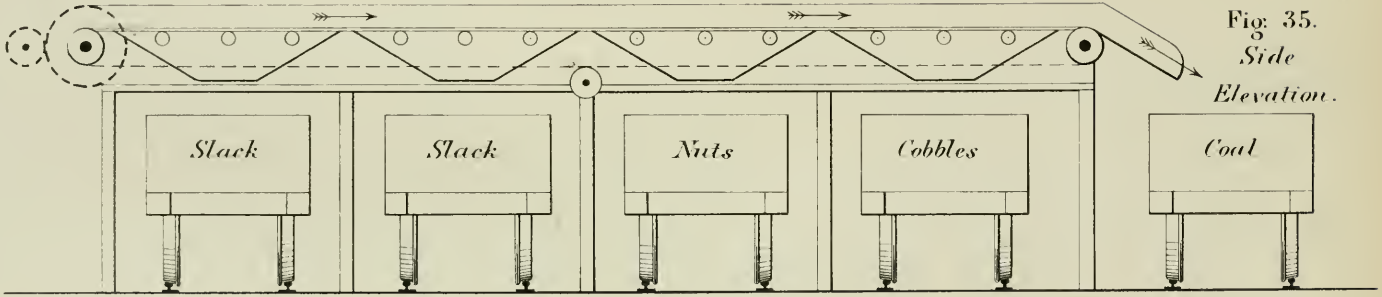


Fig. 36. *Section at S. Slack.*

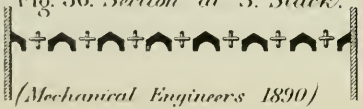


Fig. 37. *Section at N. Nuts.*

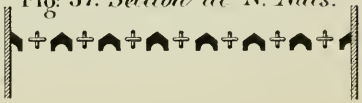
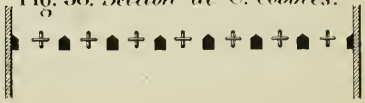


Fig. 38. *Section at C. Cobbles.*



(Mechanical Engineers 1890)

Plate 127.

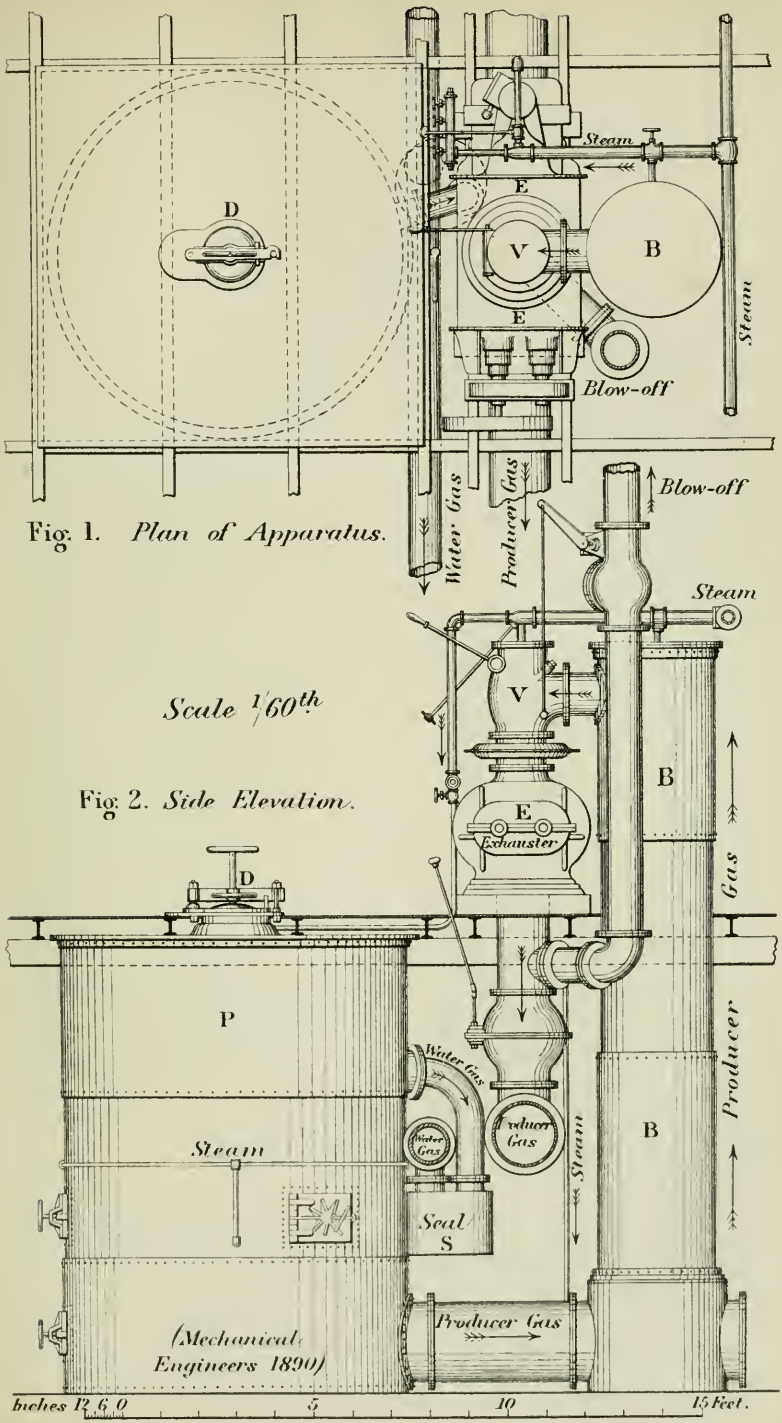
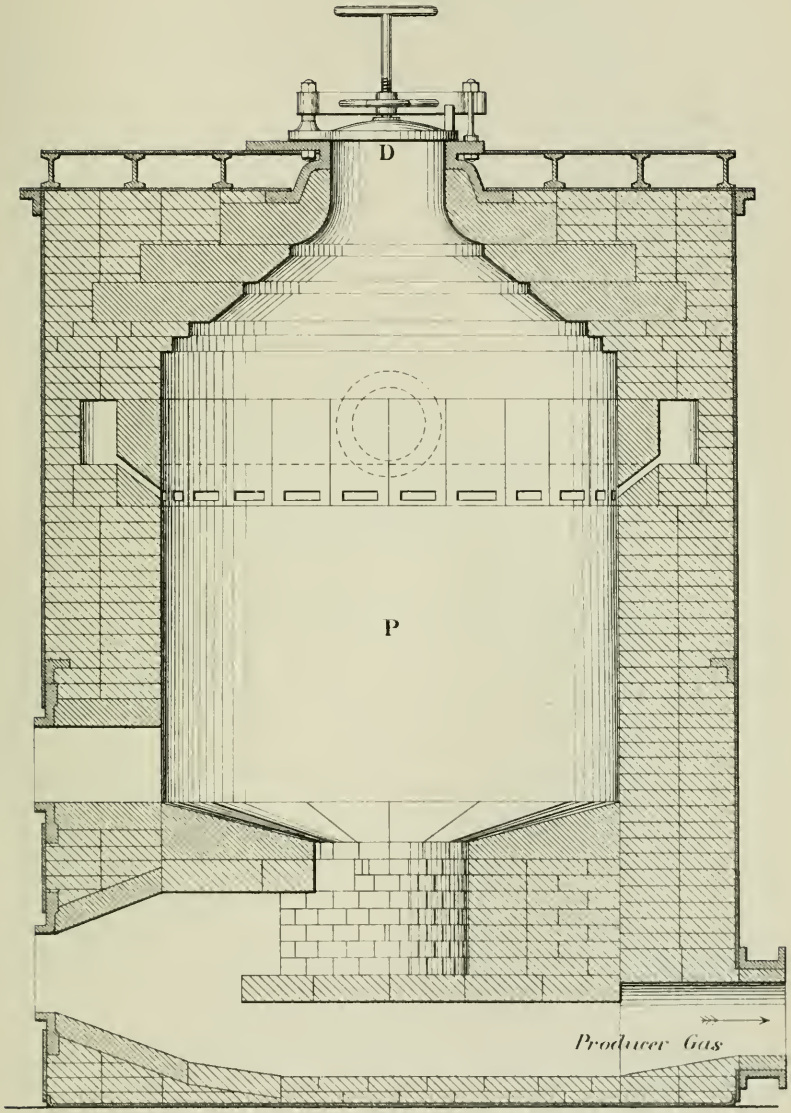


Fig. 1. *Plan of Apparatus.*

Scale 1/60th

Fig. 2. *Side Elevation.*

Fig. 3. *Vertical Section of Producer.*



(Mechanical Engineers 1890) *Scale* $\frac{1}{30}^{th}$

Inches 12 6 0 1 2 3 4 5 6 7 8 *Feet.*

Bottom of Producer.

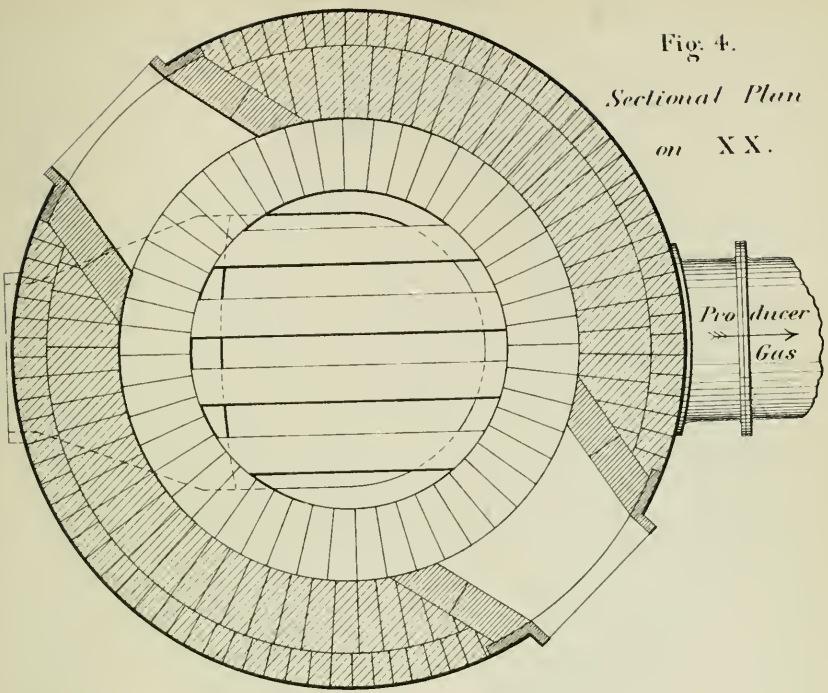
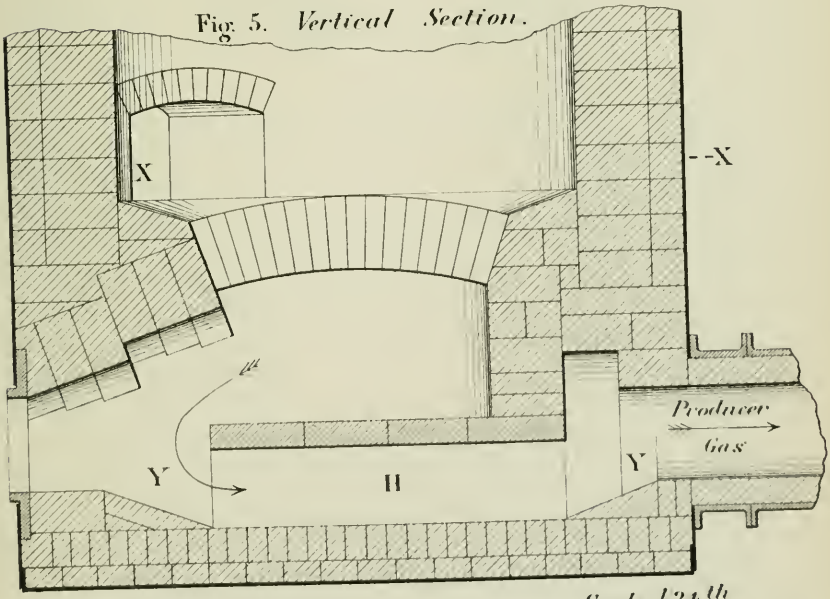


Fig. 4.
Sectional Plan on XX.

Fig. 5. *Vertical Section.*



(Mechanical Engineer 1890)

Scale 1/24th

ins. 12 6 0 1 2 3 4 5 6 Feet.

Bottom of Producer.

Fig. 6. *Sectional Plan on Y Y.*

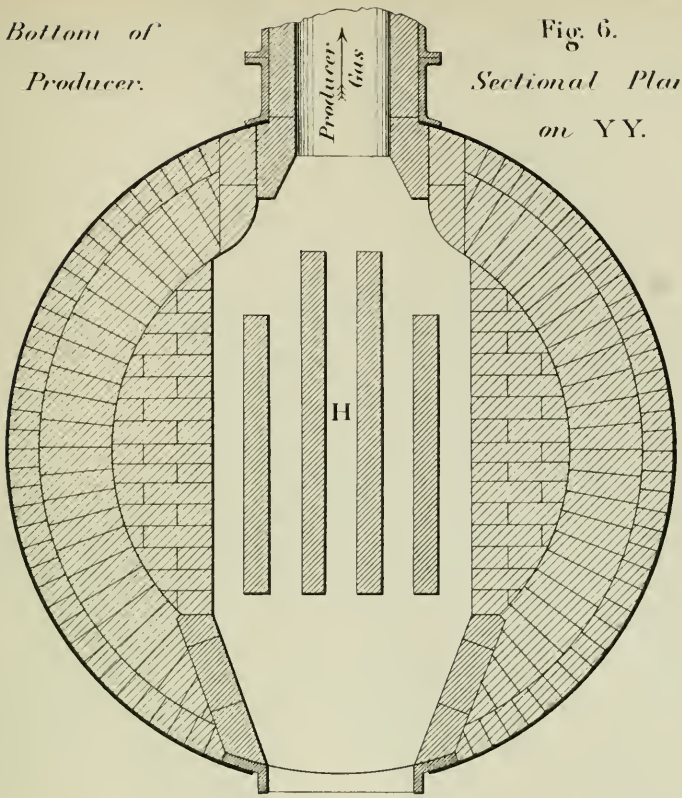
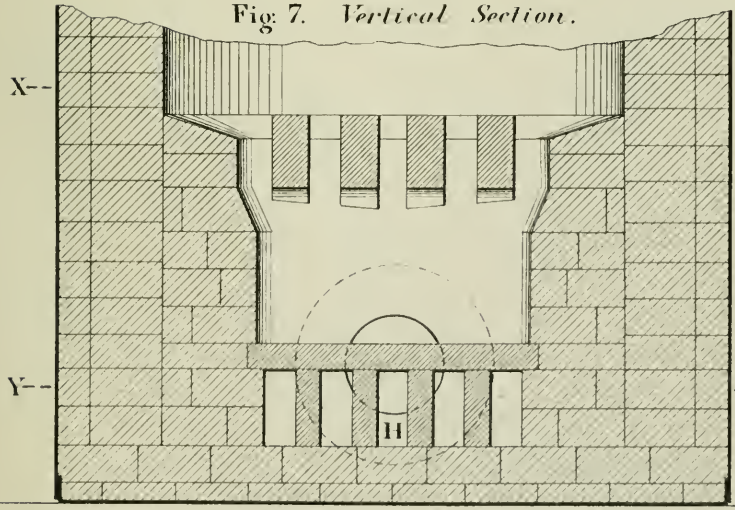


Fig. 7. *Vertical Section.*



(Mechanical Engineers 1890) *Scale 1/24 th*

Ins. 12 6 0 1 2 3 4 5 6 *Feet.*

SHEFFIELD WATER WORKS. *Plate 132.*

Fig. 1. *General Plan of Gathering Ground and Works.*

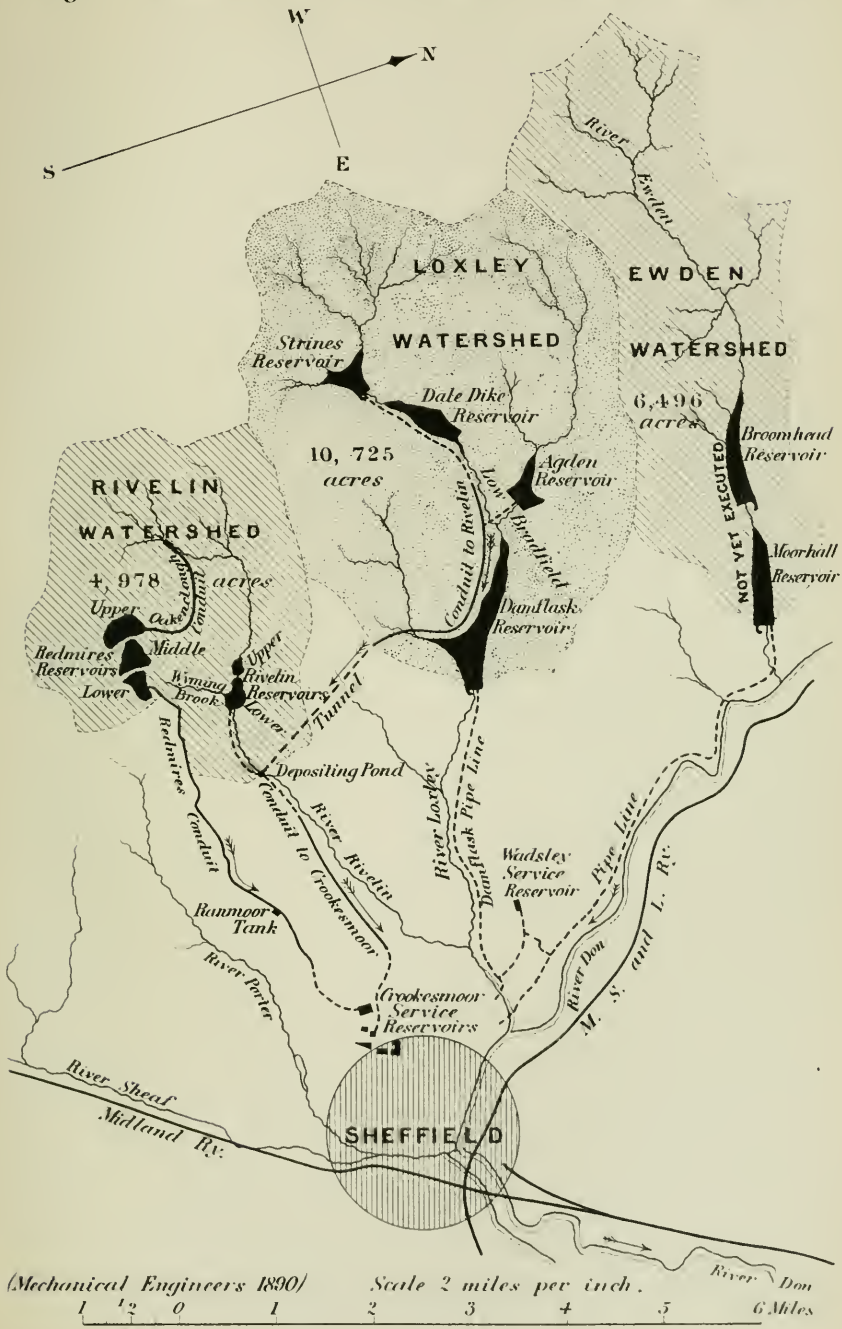
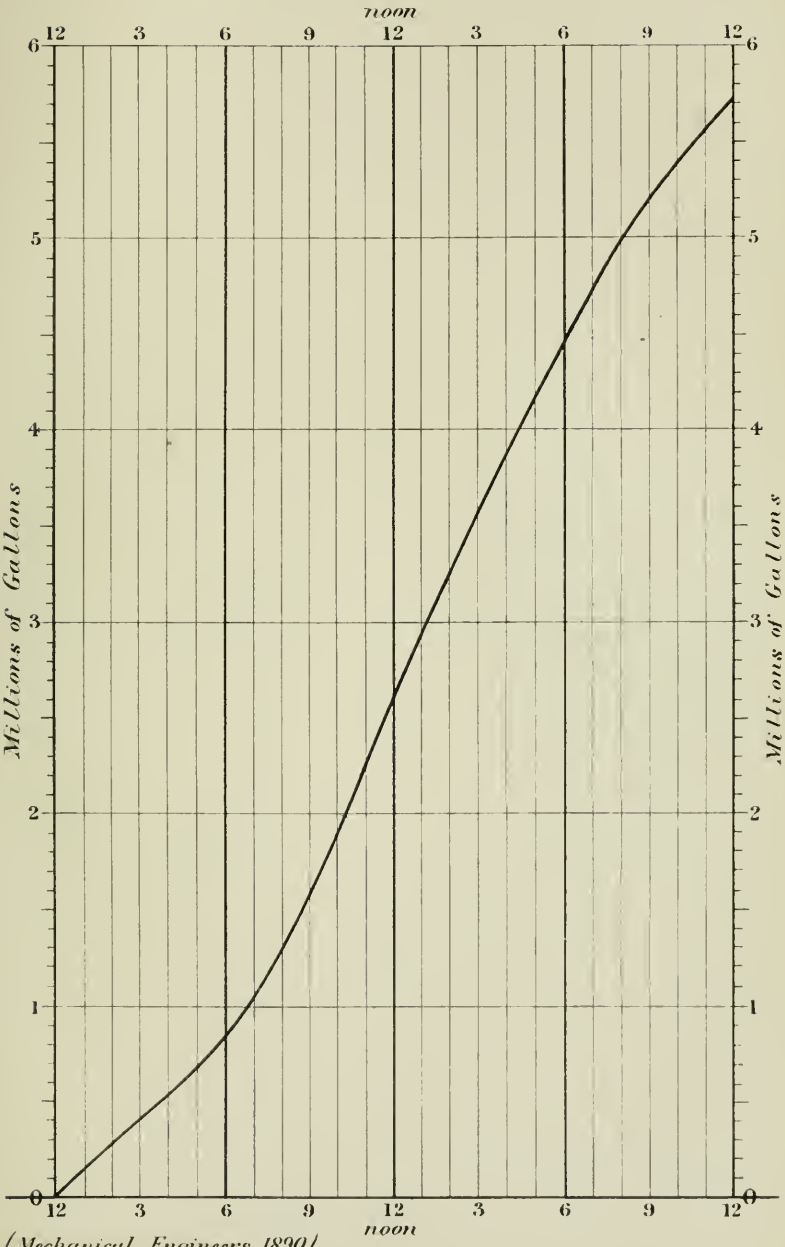


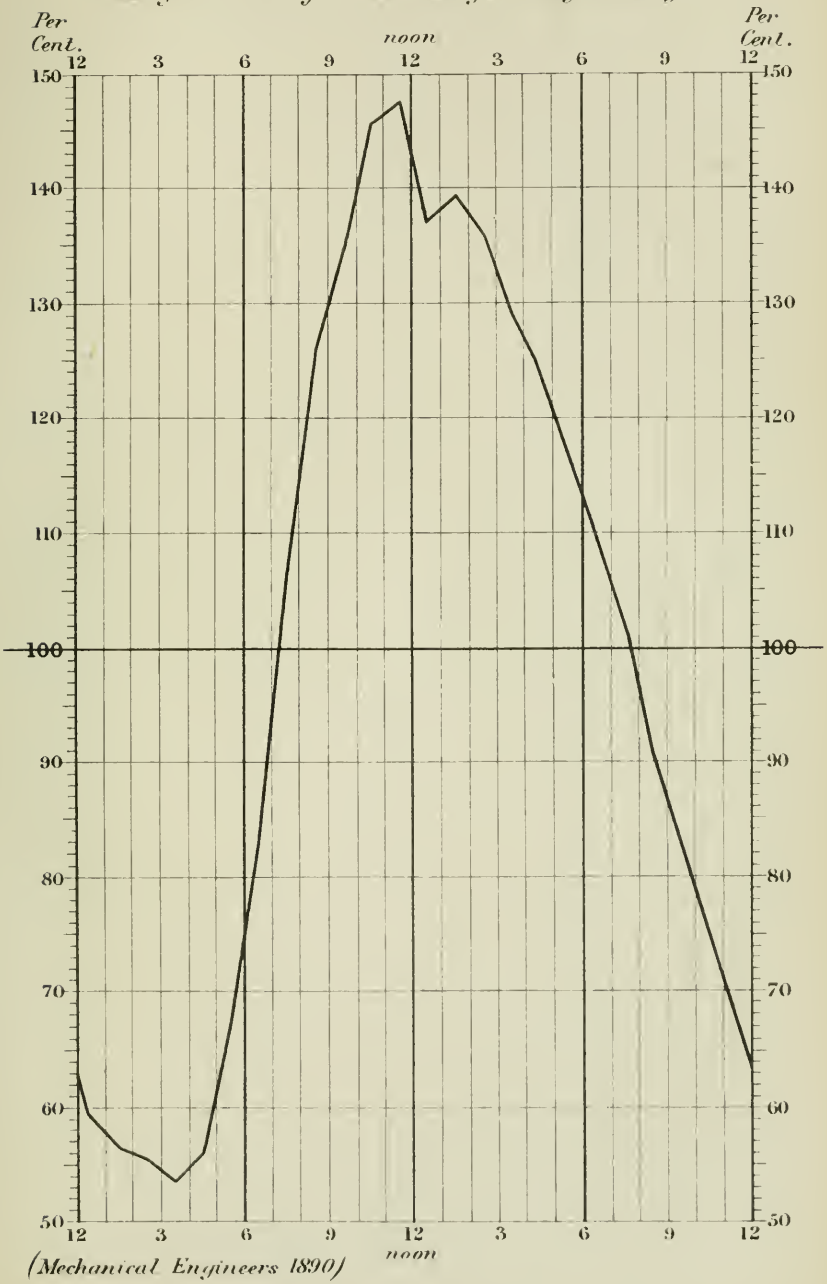
Fig. 2. *Average Daily Draught* 1878 - 89.



(Mechanical Engineers 1890)

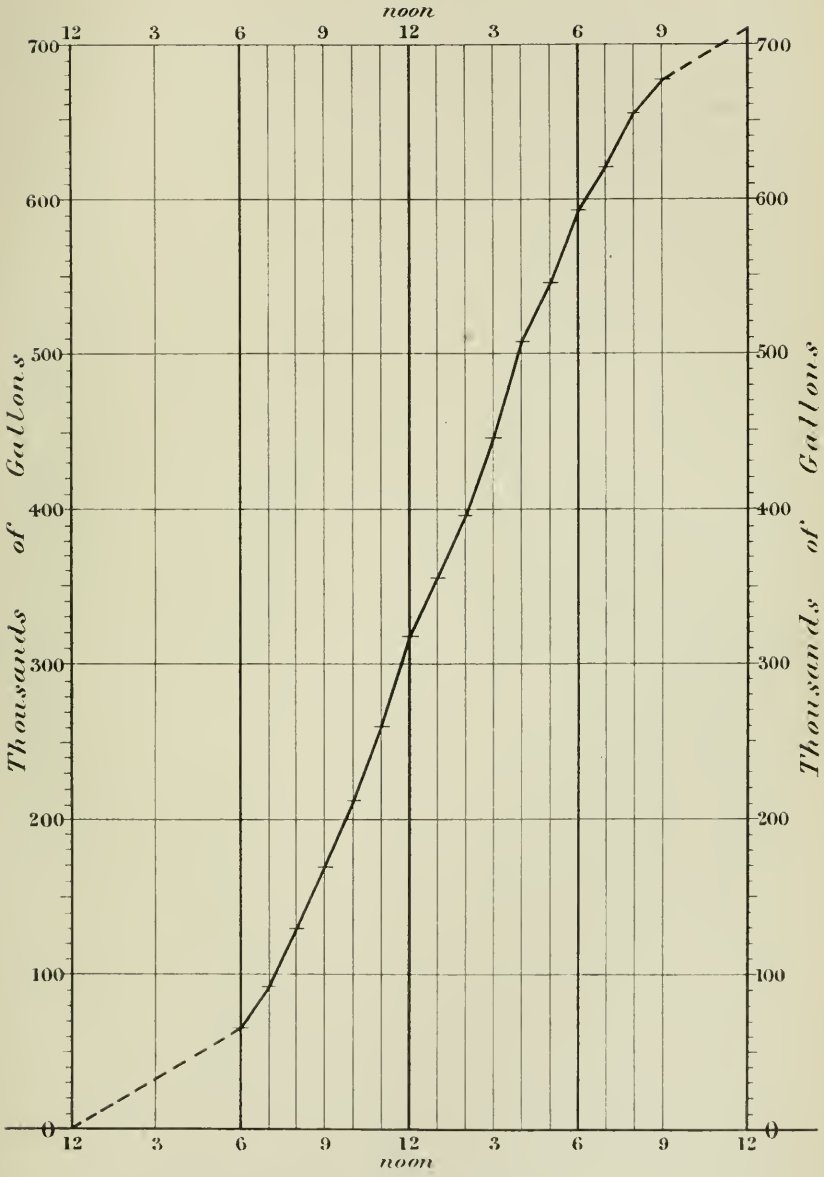
Fig. 3.

Hourly Percentage on Average Daily Draught.



(Mechanical Engineers 1890)

Fig. 4. *Average Daily Draught, April 1850.*



(Mechanical Engineers 1890)

WOLVERHAMPTON WATER WORKS. *Plate 136.*

Fig. 5. *Hourly Percentage on Average Daily Draught.*

(Mechanical Engineers 1890)

Institution of Mechanical Engineers.

PROCEEDINGS.

October 1890.

The Autumn Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, 29th October 1890, at Half-past Seven o'clock p.m.; Joseph Tomlinson, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Council had presented the cordial Thanks of the Institution, engrossed upon vellum and framed, to the Honorary Secretaries of the Sheffield Reception Committee, Professor William Ripper and Mr. R. Heber Radford, in recognition of their valued exertions in maturing the arrangements for the recent Summer Meeting in Sheffield and for the reception of the Members, whereby the success of the Meeting had been ensured and the enjoyment of the Members enhanced.

The President announced that the Ballot Lists for the election of New Members, Associates, and Graduates, had been opened by a committee of the Council, and that the following thirty-four candidates were found to be duly elected:—

MEMBERS.

Thomas James Ashley, . . .	Liverpool.
Peter Borrie Blair, . . .	Stockton-on-Tees.
John White Boyd, . . .	Hong Kong.
Walter Seckford Brewster, . .	Sydney.
Noel Chandler, ...	Hednesford.

John Richard Chater,	Madras.
George Cameron Day,	Southampton.
Robert William Grace,	Pittsburg, U.S.
William Alfred Greening,	London.
George Andrew Key,	Sydney.
Wilfrid James Lineham,	London.
John Alfred Morris,	Manchester.
John Munro,	Bristol.
Alexander John Murray,	Bombay.
Thomas Sydney Rice,	London.
John Rochford,	Dublin.
William Schroller,	London.
Harry Cecil Sheldon,	Nottingham.
Harry Shoosmith,	Birmingham.
Alfred Thomas Shore,	Bombay.
John Windle Smith,	Buenos Aires.
William Smith,	St. Helen's, Lancs.
Edward Swinerd,	Campinas, Brazil.
William Henry Watkinson,	Sheffield.
John James Webster,	Liverpool.
Edwin Edward Joseph Whitehouse,	Leeds.
Thomas Royle Wood,	Buenos Aires.

ASSOCIATES.

John Grant Birch,	London.
Edwin Perry,	Newcastle-on-Tyne.
John William Schofield,	Sheffield.

GRADUATES.

Edward Lancaster Burne,	Brighton.
Frederick Powell,	Malvern Link.
Percy Henry Sanders,	London.
Hallett Winmill,	Swaziland.

The President announced that, in accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, would retire at the ensuing Annual General Meeting; and the list of those retiring was as follows:—

PRESIDENT.

Joseph Tomlinson, ...	London.

VICE-PRESIDENTS.

Alexander B. W. Kennedy, F.R.S., .	London.
E. Windsor Richards, . . .	Low Moor.

MEMBERS OF COUNCIL.

Edward B. Marten, . . .	Stourbridge.
William H. Maw, ...	London.
T. Hurry Riches, ...	Cardiff.
William H. White, F.R.S., . .	London.
Thomas W. Worsdell, . . .	Gateshead.

All the above offered themselves for re-election.

The following nominations had also been made by the Council for the election at the Annual General Meeting:—

Election as Member.	MEMBERS OF COUNCIL.	
1859.	Richard Price-Williams, .	London.
1866.	Robert H. Humphrys, . .	London.
1869.	Arthur Keen, . . .	Birmingham.
1871.	James Platt, . . .	Gloucester.
1873.	Henry Davey, . . .	London.

The President reminded the Meeting that according to the Rules of the Institution any Member was now entitled to add to the list of candidates.

Mr. Arthur H. Hernu made the following nomination:—

MEMBER OF COUNCIL.

1878.	Arthur Greenwood, . .	Leeds.

The President announced that the foregoing names would accordingly constitute the nomination list for the election of officers at the Annual General Meeting.

Mr. J. Macfarlane Gray gave notice that at the next Annual General Meeting he should propose a motion for an alteration of the following nature in the By-Laws:—"When the total annual subscriptions paid by any Member amount to thirty annual subscriptions of £3 each, he shall thereafter be declared a Life Member of the Institution, entitled to all the benefits of membership without any further payment to the Institution." The number of years here given as thirty might be altered according to the views of the Members at the Annual General Meeting.

The following Paper was then read and discussed:—

On Tube-Frame Goods Wagons of light weight and large capacity, and their effect upon the Working Expenses of Railways; by Mr. M. R. Jefferds, of London. Communicated through Mr. Henry J. Marten, of Wolverhampton.

Shortly before Ten o'clock the Discussion was adjourned to the following evening. The attendance was 89 Members and 68 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Thursday, 30th October 1890, at Half-past Seven o'clock p.m.; Joseph Tomlinson, Esq., President, in the chair.

The Discussion upon Mr. Jefferds' Paper on Tube-Frame Goods Wagons was resumed and completed; and the following Paper was read and discussed:—

On Milling Cutters; by Mr. George Addy, of Sheffield.

The remaining Paper announced for reading and discussion was adjourned to a subsequent meeting.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers, for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated shortly before Ten o'clock. The attendance was 76 Members and 54 Visitors.

ON TUBE-FRAME GOODS WAGONS OF LIGHT WEIGHT AND LARGE CAPACITY, AND THEIR EFFECT UPON THE WORKING EXPENSES OF RAILWAYS.

By Mr. M. R. JEFFERDS, of London.
Communicated through Mr. Henry J. Marten.

The best construction of Railway Goods Wagons is a subject which up to the present time seems hardly to have received all the attention it deserves at the hands of English engineers and railway managers. Its consideration is of great importance to the problem of cheap and remunerative transport between producer and consumer, in order that the manifold industries of Great Britain may keep pace with those of other countries, which are now gradually and surely making large inroads into the business of the manufacturing and agricultural communities of the United Kingdom.

Comparing the present build of goods wagons on English railways with the wagon constructed by George Stephenson to carry the water tank for his "Rocket" locomotive in 1829, it will be observed that there has been no change in principle and but little in construction during the sixty years that have since elapsed. Goods wagons such as are still running in this country are no longer to be found in America. Those used in the United States are constructed similarly in principle to street vans, but have a king bolt or swivel pin at both ends, instead of at the front end only, so as to permit of their being turned round in their own length, and of their running round curves of a radius no greater than the length of the wagon; and they have a four-wheel truck or bogie under each swivel bolt, so as to distribute the load, and to take up any jolt caused by unevenness of road, without imparting the whole vibration or shock to the body of the vehicle and its load.

There are many ways of building these wagons. Timber sole-bars have generally been considered the best, prior to the introduction of the tube-frame now to be described. Frames made of channel iron or steel have been tried, but have been found too rigid; any shock received by them from the road is immediately transmitted back again to the rails, and the vibration tells on the many rivets holding the frame together. With timber sole-bars the limit of elasticity is reached at loads of about 20 tons, unless the wagon is made too heavy, in which case it has too much dead weight in proportion to the load it is to carry. In order to meet the requirements of modern railway goods traffic, which is being dealt with in America at only one-third of what it costs in this country, and in order to keep pace with the rapid increase in these requirements, by providing increased carrying capacity with diminished dead weight and with economy in repairs and less frequent renewals, some other material than wood is desirable for the construction of the wagons. Lightness and simplicity, combined with great strength and durability, are what is demanded; and as iron and steel have already been adopted for bridges and ships, so must they now be applied to the construction of railway wagons. A tube of any size has greater stiffness longitudinally and at the same time also greater elasticity transversely than the same weight of metal in any other form; so that at the present time the strongest and lightest goods wagons built in America, possessing also the greatest elasticity and the largest carrying capacity, are the Tube-Frame Wagons forming the subject of the present paper, designed by Messrs. Goodfellow and Cushman.

The construction of these wagons is shown in Plates 137 to 141, and general views of wagons with four different kinds of bodies are added in Plates 142 to 145. In Plate 137, Fig. 1 is a plan and Fig. 2 a side elevation of one of the low-sided or gondola wagons with drop ends, Plate 142.

Body of Wagon.—The body of the wagon, Plates 138 and 139, rests upon two transom bolsters B, one at each end, which are carried upon the bogie trucks by a ball-and-socket joint centred on a king bolt or swivel pin, with side bearings K, Fig. 8, permitting

$\frac{3}{4}$ inch vertical play or tilting, that is $\frac{3}{8}$ inch on each side. Each bolster is composed of two bars of oak, 4 ins. deep by $7\frac{1}{4}$ ins. broad and 7 ft. 8 ins. long, and is faced with channel iron along its front and back edges. The two bars are fixed together by placing one of the channel irons, flanges upwards, across two blocks or horses, and laying therein the chamfered edge of one of the bars, upon which the truss rod R is then laid in the grooves made for it, Fig. 8. Upon this is now placed the other bar of the bolster, and the other channel iron is then fixed on its chamfered edge. The whole is fastened together by four 1-inch bolts of 1 ft. 9 ins. length, their heads and ends projecting far enough to secure the pieces F for the longitudinal tubes to rest in, Figs. 4 and 18. To each bolster there are sixteen of these pieces, two of which are placed upon each end of each bolt, in such a manner that when the bolt is screwed up tight its head bears equally on the two pieces F in front of the bolster, and the nut bears equally on the two behind. The centre socket or concave plate of the ball-and-socket swivel-joint is fastened to the underside of the bolster; and flat plates M, forming circular arcs struck from the centre joint, are also fixed on the underside of the bolster, to serve as side bearings in swivelling and to prevent tilting over sideways. As these flat plates M and the bearings K beneath them are entirely hidden by the bolster B in the plan, Fig. 3, they are drawn separately alongside the bolster; and their actual position under the bolster is indicated by dotted lines. A king bolt or swivel pin, 1 ft. 5 ins. long, 2 ins. diameter in the middle of its length, and $1\frac{5}{8}$ inch at the ends, is fixed in the centre ball or convex plate of the truck bolster, and the body bolster being turned right side upwards is placed thereon. The two trucks are now placed on a straight line of rails at the proper distance apart from each other for the intended length of wagon, Fig. 2, Plate 137, with their bolsters perfectly parallel to each other, so that the body bolsters in line with these are also truly parallel, and truly at right angles to the length of the wagon body to be erected upon them.

The tubes T which form the sole-bars are of wrought-iron lap-welded, $2\frac{1}{2}$ ins. inside diameter, $2\frac{7}{8}$ ins. outside, and 33 ft. 2 ins. long. When greater lengths are used, the tubes are welded together,

as shown in Fig. 12, Plate 141, by providing a 7-inch length of double thick tube, $2\frac{1}{2}$ ins. outside diameter, and inserting this in the butt ends of the two tubes to be welded. For each wagon the tubes are eight in number, arranged in four pairs, Figs. 5 and 8, Plate 139; each pair forms one sole-bar with one tube above the other, clamped at a distance of $6\frac{7}{8}$ inches apart, centre to centre, Figs. 17 to 20, Plate 141. Four of the tubes are placed on the top of the pieces F attached to the body bolster, and four below. The ends of the tubes are adjusted to be truly parallel with the bolster; and the tubes are then fastened with clips C below and clips D above. The upper clips D are made with brackets on the top, Fig. 20, facing the longitudinal centre-line of the wagon; and upon these brackets are laid the longitudinal floor-stringers S. The ends of the tubes, Fig. 13, are ready fitted with hexagonal-headed screwed-plugs, Figs. 14 to 16, which are now unscrewed, and a bolt W is passed through each plug with the head inside, and is held in place by turning down with a hammer one of the three lips on the inside of the plug, Fig. 13. These bolts secure a malleable-iron casting to the ends of each pair of tubes, and a flat wrought-iron plate Y, Figs. 6 and 7, Plate 139, 4 ins. $\times$ $\frac{5}{8}$ inch, is laid on the top of the castings, across the end of the wagon; another plate Z of the same dimensions is placed beneath, being bent down in the centre so as to form the lower half of a hexagonal opening for the draw-bar to pass through; the upper half of the hexagonal opening is completed by a bent plate bolted upon the top of the lower plate. These two plates Y and Z, lying parallel to each other, together form the headstock of the wagon. The external centre castings for the buffers are bolted on the headstock; and the wrought-iron links I forming the headstock truss are fixed in position, and drawn up tight by their end nuts, Fig. 7. The hexagonal opening in the lower plate Z of the headstock receives the rests for the draw-frames A, Plate 138, which are placed in position between the headstock and the bolster, and are fastened at each end with strong bolts. The spring follower-plates P are put in the rectangle of the draw-frames, and between the plates are interposed the draw and buffer springs. The draw-pin is inserted through the inside follower, the springs, and the outside follower, into the hollow draw-bar, which

is itself inserted through the hexagonal opening in the lower plate of the headstock; and the draw-pin is secured in the draw-bar by a strong cotter.

When the headstock at each end of the wagon has been built up in this manner, the two tubes in each pair are clamped together throughout the length of the wagon by webs and clips, which hold them as firmly as if in a vice, Figs. 17 to 20, Plate 141. The clips and webs are made with shoulders, Fig. 20, which rest against each other when they are bolted together, and hold them from slipping upon each other in any direction, so that the bolts are relieved from all transverse strain. The truss-rod struts U, Figs. 2 and 5, two to each pair of tubes, are at the same time clamped in their places on the tubes. The four longitudinal truss-rods O are each divided in the middle of their length, and coupled by a screwed turnbuckle with right-and-left-handed threads, for screwing them up tight, Fig. 2. Bearing blocks for the truss-rods are fixed on the top of the bolster B, and the uncoupled rods having been passed through the headstock are bent over the bearing blocks and under the struts U, and coupled together in the centre by the turnbuckle, after a transverse bar of T iron has been bolted to the struts just above the rods, Fig. 5. Transverse straining rods N are fixed obliquely between the upper end of the outside struts and the lower end of the inside struts, for the purpose of distributing to the outside sole-bars any excessive weight that may be placed on the inside sole-bars. The turnbuckle is screwed up so as to draw the truss-rods tight enough to bring the sole-bars up to a perfect level. The frame is now ready for the four longitudinal stringers S of $2\frac{1}{2} \times 2\frac{1}{2}$ inches section, upon which is laid a floor of white oak $1\frac{7}{8}$ inch thick. This completes the frame and floor for an ordinary flat wagon, the sides and ends above the floor being a matter of detail which can be varied to suit the requirements of the traffic.

The low-sided gondola wagon with drop ends, shown in Figs. 1 and 2, Plate 137, may be taken as an example. For fixing the sides of this wagon, oak stakes V are used of $3\frac{1}{2}$ ins. $\times$ 3 ins. section and 2 ft. 2 ins. high, which are fastened to the upper tube of the outside sole-bar by bolts and washer-plates 4 inches square, with two opposite

corners turned in, Figs. 17 and 19, Plate 141. When the stakes are all put in place, two pine planks $2\frac{1}{2}$ ins. thick by $7\frac{1}{2}$ ins. wide and 33 ft. long, forming the sides of the wagon, are placed alongside the stakes and cold riveted to them. Flat anchor-irons, with $2\frac{1}{2}$ ins. at the top bent at right angles to go over the sides, and at the bottom made round and screwed to pass through the floor, are fastened to the upper tube of the outer sole-bar by malleable-iron pieces J, Fig. 5. The upper edge of the top plank is notched out to receive the hooked end of the anchor-iron, and the latter is then passed through a hole made for the purpose in the floor, the piece J is placed on it, and a nut underneath is screwed up as tightly as possible; after which the anchor is riveted to the sides with cold rivets and washers. The strap-iron coping, bored by templet for wood screws to pass through the hook of the anchor-irons, is fastened on the top of the side boards for their protection. The sides being thus completed, the drop ends are fixed by putting $2\frac{1}{2}$-inch angle-iron anchors, with round screwed end, through the floor 3 inches from the inside ends of the sides; they are fastened the same as the side anchor-irons, the flanges being used to keep the end from falling outwards. Two planks $2\frac{1}{2}$ ins. thick by $7\frac{1}{2}$ ins. wide and 7 ft. 2 ins. long are fastened together by two $\frac{1}{4} \times 2$ ins. straps, passing round the bottom and up both sides and cold riveted. Under the straps the end boards are notched out 4 ins. wide and 1 inch deep, to hold a link, the other end of which passes through an eye-bolt; the latter passes through the floor, and is held firm by a nut, thus forming a hinge upon which the end boards turn. The longitudinal truss-rods O are now finally tightened up a little more, so as to give the body of the wagon a slight camber. With the exception of painting and oiling, the wagon is then complete and ready for service.

Bogie Trucks.—The four-wheel bogie under each end of the tube-frame wagon is of the kind known as the "diamond" truck, from the diamond shape of its two side-frames. It has now been in use more than forty years, and has never been found defective in any respect; it is therefore the standard truck on all American railways. For lightness, strength, and simplicity of construction, it has never been

equalled. There is not a rivet in it to be cut off by vibration; and the bolts that hold the parts together are subjected to little or no strain. The construction is shown in Figs. 8, 10, and 11, Plates 139 and 140.

Instead of the horn-plates or axle-box guides of an English railway wagon, a pair of slide-columns L, Fig. 10, are bolted front and back on each end of a transverse oak spring-plank Q, which is 12 ins. wide by 5 ins. deep and 7 ft. 3 ins. long; each pair is fixed by four $\frac{5}{8}$-inch bolts, $14\frac{1}{2}$ ins. long, of which the nuts and heads are alternately on opposite sides of the plank. Above the plank is an oak bolster E, of the same length and width but 8 ins. deep, sliding between the columns L, between which it is guided at each end by a pair of slides fitting the columns and bolted on the bolster. Two pairs of wheels and axles are placed 5 feet apart, the axle-boxes are set on the journals, and the brasses or bearings placed in the boxes and secured with keys. Inverted-arch bars G of best wrought-iron, $3\frac{1}{2}$ ins. broad by 1 inch thick, are laid on the top of the axle-boxes, and bolts are placed temporarily in the outside holes to keep the wheels from spreading apart. The spring plank Q is laid across the inverted-arch bars, midway between the wheels; two nests of bearing springs are placed on the top of the plank; and the bolster E is placed on the top of the springs. Each nest of springs is graduated, and contains one heavy and two light coils or spirals, the small springs to carry the body of the wagon and light loads, while the larger ones come into play for heavier loads. The temporary bolts are now removed, and a top arch-bar H of best wrought-iron, $3\frac{1}{2}$ ins. by $1\frac{1}{8}$ inch thick, is laid over the bolster, its ends resting on the ends of the inverted-arch bar on the top of the axle-boxes. The slide-column bolts are put in place, and a bottom tie-bar $3\frac{1}{2}$ ins. wide by $\frac{5}{8}$ inch thick is put under the axle-boxes and the inverted-arch bar, and is secured by the nuts on the bottom of the column bolts. The bolts fore and aft of each axle-box are put in through the two arch-bars above the box and through the tie-bar below, thereby securing the whole frame together, and keeping the axle-boxes in place. The bolster E is trussed by a pair of rods, bent under the central block beneath the bolster, and drawn up tight by a nut bearing against a washer plate on each end of the

bolster, Figs. 8 and 11. The centre ball or convex plate of the ball-and-socket swivel-joint is fixed on the top of the bolster; and the side bearings K, which are hollowed out to form oil cups, are placed in holes made for them in the bolster. The truck is then complete, ready for the brake hangings, as shown in Figs. 4 and 8; and the two trucks are made exactly alike, all their parts being interchangeable.

Wheels.—The truck wheels are made from a mixture of best charcoal iron and selected scrap, in the proportions required for chilling; and are cast in metallic chills. When cool enough to be taken from the moulds, they are placed in a red-hot pit and covered up, and allowed eight to twelve days to cool. This extent of annealing renders them very tough. They are capable of standing at least the test of a weight of 140 lbs. falling 12 feet and striking centrally on the hub or boss four times, the flange of the wheel being placed downwards and resting upon three supports on an anvil block of 1,700 lbs. weight, which is set on rubble masonry 2 feet deep. When ready for the axle they are forced on it with a pressure not less than 35 tons and not exceeding 45 tons.

The average life of these chilled-tire cast-iron wheels is more than 120,000 miles, and the advantage they present over steel-tire wrought-iron wheels is fourfold:—they cost very much less, are 20 per cent. lighter, run a third further, and when worn out can be sold as scrap for 80 per cent. of their original cost. Their present cost at New York is 36*s.* each; and in replacing old wheels by new ones in the United States, the old wheel together with 6*s.* will buy a new one. The steel-tire wrought-iron wheel after running about 22,000 miles has for safety to be turned up, which process it will stand three times, giving a total of about 90,000 miles. The flanges soon get rough and torn, and too thin and sharp for safety; whereas those of the cast-iron wheels soon become smooth and highly polished, the chilled iron being much harder than steel. When no longer fit for service, the value of the steel-tire wrought-iron wheels must be little enough, judging from the numbers of them that are to be seen lying on the scrap heaps of the railways on which they have been used. Experience

on the Belgian State Railways with the tube-frame wagon has shown that the standard steel-tire wrought-iron wheels there adopted will not stand under the heavy loads intended to be carried on the same wagon with chilled-tire cast-iron wheels; they have recently broken down under a load of 35 tons.

Axles.—The truck axles, Fig. 8, Plate 139, are 5 ins. diameter through the wheel boss, and $4\frac{1}{2}$ ins. in the centre, with journals 4 ins. $\times$ 7 ins. They stand without fracture three blows with 12 feet fall, followed by two blows with 18 feet fall, of a weight of 1,640 lbs. striking midway between supports 3 feet apart, the axle being turned over after each blow.

Brakes.—The brakes used are known as "inside hanging brakes," Figs. 4 and 8, Plates 138 and 139. The brake blocks holding the brake shoes are attached to the ends of a transverse beam, which hangs suspended by links from the truck bolster, and carries the brake-lever fulcrum in the middle of its length. The short ends of the pair of levers are coupled by the bottom tie-bar. The top of the inner lever rests in a forked guide-plate with graduated pin-holes, and the top of the outer lever rests on a round-iron guide. A chain attached to the top of the outer lever leads thence to the brake shaft, round which its other end is wound. This shaft is provided with ratchet-gear, which is worked by the foot to hold the brake in place. The levers can be worked by hand, or by any system of air or vacuum brake, or with side levers if necessary.

Strength of Wagon.—The tube-frame wagon with its two bogie trucks and chilled-tire cast-iron wheels has a breaking strength of 300 tons. A good illustration of its strength is furnished by the use of 112 of these wagons in April 1888 for moving back the Brighton Beach Hotel at Coney Island, New York, a total weight of more than 6,000 tons. After 24 tracks had been laid in the sea, and the 112 wagons had been placed in position upon them under the hotel, and the weight of the load brought to bear upon the wagons, there occurred a great storm lasting from 12th to

15th March, which so delayed the work of extending the lines in the rear of the hotel that the wagons had to continue supporting its entire weight for more than six weeks. After it had been moved inland through the required distance of 595 feet, none of the wagons showed any sign of being overstrained, though some of them had been carrying loads exceeding 120 tons. At the finish there was not a timber or board of the hotel broken, nor a crack or opening in any of the joints or angles of the building, nor had a pane of glass or a chandelier been injured, so uniformly had the wagons stood up to their work. In its new site this large hotel is therefore a standing witness to the excellence and efficiency of the tube-frame wagons. The identical wagons which were employed on this work have been in service ever since, carrying daily loads of 30 to 35 tons, without costing anything for repairs other than re-painting.

Flexibility.—When the line is uneven, the rigid and cumbersome wagons used on English railways sometimes stand on three wheels only, the fourth being held up above the depression in the rail by the rigidity of the frame. The same is the case with bogie trucks having rigid frames; and for this reason, together with the excessive cost for repairs, the use of rigid square or rectangular frames for the bogie trucks of goods wagons has been abandoned in America, and the flexible diamond-frame truck has been adopted instead. This truck can run round a curve, of which the radius is equal to the square of its wheel-base; and in a properly constructed truck the wheel-base should be the same as the gauge. Thus on the 4 ft. 8½ ins. gauge the diamond truck can run round a curve of 22 ft. radius. Two wagons rounding a curve of 55 ft. radius are shown in Fig. 9, Plate 140. Prior to actual trial of bogie trucks, it has sometimes been erroneously supposed they will never do for the goods traffic on English railways, in consequence of the speed that is required in this country. In running round any curve there is always a lateral pressure of the wheel flanges against the outer rail, proportionate to the momentum of the wagon and its load. But with a bogie truck at each end, the weight of the wagon body and its load rests upon the ball-and-

socket bearing in the centre of the truck, so that the wheels have free play to adjust themselves to the curve, and can more easily run over any obstacle or unevenness in the rails, without imparting the jolt to the body of the wagon and its load. This is the reason why a locomotive can take a train of 40 tube-frame bogie wagons loaded with 30 tons each as easily as a train of 32 ordinary English wagons loaded with only 8 tons each. Both the inertia of the train and the resistance it encounters from the road are more easily overcome with bogie trucks than with four-wheel wagons having no radial axles. As an evidence of durability, a photograph is shown of several diamond-frame trucks that were washed $4\frac{1}{2}$ miles down the bed of the Junietta river at the time of the Johnstown flood of 1st June 1889; and when taken out they were put in service again at a very small expense, the principal loss being the wooden floors and sides and one third of the original cost of the tubes.

In commenting upon the construction of the long tube-frame bogie wagons, a German engineer, Mr. Henri Macco, who is one of the directors of the German State Railways, has recently remarked that in building new goods wagons the object should be to increase their carrying capacity and diminish their tare weight; but the realisation of this aim is limited with the present build on account of the rigid wheel-base. The longer the wagons, the further apart must the axles be; the greater will then be the resistance in running round curves, and the larger the expenditure for locomotive power and for maintenance of rolling stock and permanent way. With a bogie truck at each end he points out that the length of the wagon is quite independent of the distance between the axles in the truck, as well as of the sharpness of the curves. It is by means of the bogie trucks that the American railways have been able to increase the paying load of their goods wagons to 20 and 30 tons; and there is the prospect of its being further increased before long to 40 tons. The weight of the tube-frame wagons of 34 feet length which are now running on the Furness Railway is 8·3 tons, and the load they carry is 30 tons; while the ordinary wagons in use on that railway weigh 6 tons and carry 8 tons, their length varying from 18 to 20 feet.

Maintenance and Repairs. — The only expense required for maintenance is the renewal of brasses, and re-painting every second year.

From the manner of building the wagons it will be seen that there is little or nothing to get out of order or to repair. All ordinary repairs can be made in a few minutes, while the wagon is loaded and standing in the train. If a bearing is to be examined, the axle-box can be lifted an inch by a lever or jack placed under it, the key and bearing taken out, and the latter if necessary replaced by a new one, in less than five minutes. If a pair of wheels is to be taken out, a jack should be placed on each side of the truck under the bolster column, and the truck raised sufficiently to ease the wheels; the outer bolts are removed, and the nuts of the inner bolts loosened; the wheels and axle can then be pushed out by pressing the boxes outwards with the foot, and a new pair of wheels put in; with new wheels and axle at hand, the whole process requires less than fifteen minutes. If any of the struts, straining rods, or malleable castings should be broken, which however has never yet occurred even in a wreck, they are all numbered and could be telegraphed for, or could be taken off from another tube-frame wagon, if an empty one happened to be on a siding near by, as all parts are interchangeable.

An illustration of total wreck is furnished by one of the photographs exhibited. In this case the woodwork above the tube-frames was a total loss. The badly bent tubes were taken back by the tube makers, and new tubes were delivered at one-third of the original cost. The castings were not injured, and 98 per cent. of them were used in building new frames. In another instance one of the low-sided gondola wagons that was loaded with 30 tons of pig-iron got off the rails, and ran over the sleepers for about its own length, springing up and down in the middle as it went over each sleeper. Instead of the tubes being twisted out of shape, as might have been expected, and the wagon otherwise badly injured, it was found to have sustained no damage whatever. This may be considered one of the severest tests that any wagon could pass through without damage; and it may be doubted whether any other wagon could have stood it, loaded as this one was. Immediately after the accident the

same wagon was sent a distance of 1,800 miles with 27 tons of castings, and has been in active service ever since.

Railway Working Expenses and Goods Rates.—According to the facilities and cheapness of transport by rail in other countries will their surplus products be pressed upon Great Britain. At the present time for every hundred tons of grain he sends to London a farmer living 1,000 miles inland in the United States has an advantage of £30, after paying both land and ocean transit, over a farmer living at Stirling in Scotland, only 420 miles from London. Why should railway rates be so much lower in America than in England? The answer sometimes given is because the English railways have cost nearly three times as much to make as the American. Although this is very true so far as it goes, it is no reason why the haulage of goods should cost the English railways three times as much as it costs the American. If it costs more on a good line than on a bad one, why have the better line?

In 1889 the average rate charged for all descriptions of goods on all the railways in the United States, including terminal charges, was only 0·488 penny per ton per mile, while the average cost to the railways was only 0·311 penny. The average dividend on highly inflated shares was 3·3 per cent. The average earnings and working expenses of the three best lines in America, or those that compare most favourably in construction with the English railways, are as follows:—

	New York Central.	Pennsylvania.	Philadelphia and Erie.
Earnings per ton per mile . .	0·38*d.*	0·313*d.*	0·278*d.*
Working expenses per ton per mile	0·28*d.*	0·201*d.*	0·176*d.*
Annual earnings of each locomotive	£7,200	£7,610	£7,000
Dividends per cent. . . .	4½%	5%	5%

Compared with these, the London and North-Western average earnings are estimated at 1·25 penny per ton per mile, with a cost of 52 per cent. or 0·65 penny per ton per mile for working expenses, while the average earnings of each locomotive in 1888 were only £4,100. The average annual earnings of each locomotive in 1889 on all American railways, good bad and indifferent, were £6,590;

while the average annual earnings of each locomotive on all the railways in the United Kingdom were only £4,837.

Since 1865 the railway rates in the United States have been reduced fully 79 per cent., so that the railways are now rendering for £21 the same service for which in 1865 they charged £100. The reason they have been able to make so great a reduction is that they have gradually improved their goods wagons, which would formerly carry loads of their own weight only, until they will now carry three or four times as much. Within the past ten years the Pennsylvania Railway has changed nearly its entire goods rolling stock from wagons that weighed 10 tons and would carry only 12 tons to wagons of the same dead weight which will now carry a load of 30 tons and even up to 40 tons. The strong competition of navigation on the rivers and lakes, and on canals constructed at the public expense, has stimulated railway ingenuity to the utmost in America; and even with the low rate of working expenses which has already been reached it is not considered that the minimum has yet been attained. On the English railways during the past thirty years neither have the goods rates undergone any reduction, nor have the working expenses been lessened so that the rates could be lowered and still yield fair profits. As to the opportunities there are likely to be in this country for loading fully the larger wagons such as are running on the American lines, it must be borne in mind that 72 per cent. of the freight traffic on English railways consists of coal and other minerals, which are carried in full wagon loads at the present time. The proportion of coal and other minerals to the total freight carried on English railways is much greater than on American lines. Thus the freight traffic on the Great Western Railway in 1888 was 75 per cent. minerals and 25 per cent. general merchandise; while that on the New York Central in 1889 was only 30 per cent. minerals to 70 per cent. general merchandise. The traffic of the latter railway is carried wholly in large bogie wagons.

One of the great objections sometimes urged to the use of long wagons on English railways is that the turntables are not large enough. In America turntables are never used for wagons. The bogie trucks permit of using curves of one chain or 66 feet radius,

whereby a whole train of wagons can be shunted by a locomotive on a right-angle siding in less time than four or five men with a horse could turn two short wagons on a turntable. Another objection occasionally made to the bogie wagons is that they are too long for the present weigh-bridges. Most of the weigh-bridges in the United States are made for wagons 32 feet long; but there are hundreds of wagons 40 feet in length that pass over them and are weighed daily, one end at a time. It certainly requires less time and expense to weigh one wagon with 32 tons load by weighing one end at a time, than to weigh four wagons of 8 tons each. The centre of gravity of any load cannot be changed without taking off or adding to some portion of the load itself; and the sum of the two weighings of the long wagon, one end at a time, is the same as if the whole wagon were weighed at once on a weigh-bridge long enough for the purpose. Thus two of the principal objections to the long wagons can be overcome by doing the work in the simplest, cheapest, and most expeditious manner. New weigh-bridges are continually being bought; and as a 50-ton weigh-bridge 32 feet long can be purchased at less than £150, the expenditure sinks into insignificance when compared with the saving it will effect.

On the railways in the United Kingdom there are now about a million wagons, with an average carrying capacity of 7 tons each; and for renewals and extensions about 100,000 are added annually, costing an average of about £60 each, or a total of £6,000,000. Were the tube-frame wagons adopted to the extent only of this yearly addition of carrying capacity, and used in places where they could get full loads, the change could be effected without any strain upon the finances of the railways, as only 24,000 of them, costing an average of £165 each or £3,960,000 altogether, would be required to carry the same tonnage, being £2,040,000 less than the railways are now expending. The benefits derived from the lightness and flexibility of the new rolling stock would tell so greatly upon the profits that the present rigid four-wheeled wagons would soon be entirely discarded. The cheapest goods traffic in the world is at the present time being carried on by means of these tube-frame wagons, whereby the yearly saving in working expenses is more than

equal to the annual dividend on any railway using them ; and no line can compete for traffic with a rich rival, unless it secures for itself the powerful aid derived from the ability to carry heavy loads in light wagons, as against light loads in heavy wagons.

Discussion.

Mr. Jefferds exhibited a number of photographs of the tube-frame wagons, showing the adaptation of this method of construction to high-side and low-side goods wagons, hopper coal wagons, and various other kinds of wagons in ordinary use ; and showing also the nature of the injuries sustained by these wagons in accidents. He also showed specimens of the tubes and clamps, and of the weld made in joining two lengths of tube together. The principal feature in the tube-frame combination, he pointed out, was the mode of clamping the tubes together in pairs, the clamps being made of malleable cast-iron, which had a tensile strength of 50,000 lbs. per square inch, and could be bent over to a right angle without fracture, and twisted round to a considerable extent without breaking. The bolts and nuts holding these clips together were not subject to any transverse strain whatever, all such strains being prevented by the shoulders upon the clips themselves.

Mr. W. A. Adams understood one object of the paper to be to illustrate the fact that in England far more dead weight than paying load was carried. In 1876 he had himself read a paper before the Institution of Civil Engineers (vol. xlvi, page 100), in which he had dealt very fully with this subject, and had illustrated it at great length by the practice of English, French, and American railways. Since that time the Americans had advanced very much in the reduction of dead load, or rather in the increase of paying load. In this respect the French had been much in advance of the English at

that time: the goods traffic on the Western Railway of France was conveyed in high-side wagons holding 10 tons, and weighing only 3·45 tons, notwithstanding that they were fitted with buffer springs and buffer rods, which of course increased their weight. In the present paper it was represented that by the use of bogies the wagons could be much improved with respect to the ratio of the paying weight to the dead load; and that there was a much greater advantage in using tube frames than in using frames of wood flitched with iron. The English practice was to carry the wagons on four wheels; the American practice was to carry them on two bogies with four wheels each. The question however of the load carried in a wagon was not whether there should be eight wheels on the bogie principle or four wheels on the English plan; the question was, what should be the load upon each wheel. On a good road he considered that the cost of traction per ton was the same for a four-wheeled wagon as for an eight-wheeled. Supposing the load per wheel to be three tons, the former would carry twelve tons and the latter twenty-four. In the four-wheeled wagon the wheel base would have to be 9 feet, and in the two bogie trucks of the eight-wheeled wagon it would be about 4 ft. 8 ins. There had lately been some extraordinary letters in the daily papers with reference to the low cost at which freight was conveyed in the United States, in consequence, as it was said, of the use of bogie wagons; reference was not made to tube-frame wagons, the question being whether the load was carried on a four-wheeled wagon or on eight-wheeled trucks. It was stated in the paper (page 485) that on the Furness Railway the ordinary wagons weighed 6 tons and carried a load of 8 tons; he could only say that such a proportion would reflect upon the designer and the constructor. The reason why in England the road was overloaded and the wagons made heavier than they otherwise need be, he imagined was that the object desired was to reduce the cost of repairs—not of construction, because the heavier the wagon, the more material it took, and the more its construction must cost. If a coachmaker were asked to build a landau and to make the felloes and the frame and body of a lighter section than usual, he would probably object that the carriage would wear out

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much faster and would be oftener in for repairs. To which the reply would be that the repairs of a landau did not cost nearly so much as horses and their keep. It was the same with a railway: something might be saved in repairs by heavier construction, but at the expense of locomotive power. If the conditions for traffic in England were the same as in America, two English four-wheeled wagons could be constructed to carry 24 tons as readily as an American wagon would carry 24 tons. He did not see what there was in the bogie truck that should diminish the traction. If it were urged, why then did the Americans prefer to convey traffic on bogies? the answer was that, in the commencement of railways in America, the roads were so bad that they could scarcely indeed be called roads; they were mere tracks. Ditches were cut along each side, and the stuff was thrown on the middle of the track, upon which the light sleepers and rails were laid. On such a road the traffic of English wagons and locomotives could not be carried. Two small short bogies were therefore constructed, with small wheels from 18 to 24 inches diameter, upon which was placed a body, and with that vehicle a load was carried of 6 to 8 tons. Those bogies, low-wheeled and short, wobbled in and out as they ran along the road, and just managed to get along with their load. Such an insufficient contrivance was a necessity in the early days of American railways, in order to get through the work; but the English railways were different. The American construction of railways having once been set, and bogies started upon them, the plan had been persevered in, and it had now become difficult to get out of the groove. If he were called upon to construct a railway for opening up a new country, like central Africa, he should certainly begin as the Americans had done, and throw the stuff from the ditches on the centre of the road, and lay upon it a track of 2 or 3 feet gauge, on which he should put two light bogies with a body of some sort, and a light engine that could just get along, the whole construction being extremely small and cheap. But as the traffic grew, he should abandon that type at an early stage and resort to the English plan.

Although some allusion had been made in the paper to the question of how these long bogie wagons were to be dealt with in England, he did not think that all the difficulties had been

weighed. In the first place, it should be borne in mind that in England outside buffing could not be done away with; and with outside buffing it would be impossible for the wagons to work round a curve like that shown in Fig. 9, Plate 140, of 55 feet radius. In America such curves were managed only by having all the buffing nearly central, as well as the traction. Then again there was the question of the turntables. If one of these eight-wheel bogie-wagons were running in North Wales, round short curves and up and down hill, what convenience would there be for loading and working? It would be singularly inconvenient. He did not know what the practice now was in Pennsylvania and in New Jersey, but he knew what it used to be. A large amount of the coal traffic of those countries used to be carried in four-wheeled wagons, which were almost the counterpart of the old wagons on the Taff Vale Railway, because it had been found that the eight-wheel bogie-wagons were not suitable for a hilly and difficult country like those. In page 485 of the paper there occurred what to him was an extraordinary statement, that 40 tube-frame bogie-wagons loaded with 1,200 tons altogether could be drawn with no more locomotive power than 256 tons of load carried in 32 English four-wheeled wagons. This seemed to him so amazing that unless it was backed up by actual facts he certainly thought there must be some error. With the remark in page 488 he quite agreed, that ten years ago the goods traffic on the Pennsylvania Railway used to be conveyed in wagons weighing 10 tons and carrying only 12 tons. It should be borne in mind that in those days the Pennsylvania Railway branches—not the main line itself—were inferior; and therefore the new wagons carrying 24 tons, built for good roads having runs of 2,000 and 3,000 miles, could not work upon those inferior branches. If there were the same conditions of traffic in England as in America, one of those long wagons would be loaded at 2,000 or 3,000 miles from the port with 24 tons or more, and would be coupled in a long train, and taken along a road with the easiest of gradients and curves. In America such a train was drawn by what was called a "consolidation" engine, which had eight coupled wheels, and a two-wheeled pony truck in front. Any road that would carry those engines, which

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conducted the chief through freight of America, would readily enough carry a four-wheeled wagon with 9 feet wheel-base.

Mr. Bernard Dawson asked whether some of the difficulties of using these long wagons on English lines had been sufficiently considered. Taking the traffic of a small road-side station, there might each morning be as many as four or five wagons from London, Manchester, Liverpool, or other large stations, as well as wagons with coal and lime and other undamageable goods; and if there were to be none but these long wagons, containing perhaps only from 2 tons to 5 tons each, the sidings would have to be considerably extended in order to receive five or six different consignments. There would also be some difficulty in dealing with the wagons in the hydraulic hoists in large goods stations, where there were three or four tiers of floors; and great expense would be involved at some stations, as at some of the London termini, at Manchester, at Edgehill, and places of that kind. Some idea he hoped would be given of the cost of maintenance of these wagons on the Furness Railway, and also as to what they were principally loaded with. The two entire truck-load freights going any real distance on the Furness line were the iron ore from the mines to the blast-furnaces, and the pig-iron from the Barrow and Ulverston district to Sheffield. He should be glad to know whether the long wagons were used for station to station traffic, or whether only for undamageable iron, or whether also for goods that required to be protected with tarpaulin sheets; and how it was proposed to deal with the trans-shipment of the loads at junctions, and with small consignments. The average loads of light damageable goods on English railways he believed did not exceed 7 or 8 cwts. It would be a serious thing to have to use wagons 32 feet long for taking loads of even 30 cwts. of sheeted goods. He did not know whether the American railways were covered with facing points, sidings, and locking bars; but he certainly did not see how the traffic of crowded station-yards, with facing points and gridiron sidings like those at Edgehill, could be worked with wagons 32 feet long. It would necessitate a re-arrangement of most of the large goods yards to accommodate wagons of that length, however short might be the wheel-base of the bogies.

Mr. William Evans, general manager of the Cyfarthfa Iron and Steel Works, thought it would be advantageous to the freighters in South Wales to have wagons carrying much larger quantities than the existing wagons could carry. For carrying iron ore and other materials for the supply of blast-furnaces, he thought there was one deficiency in the construction of the larger wagon described in the paper. For instance, where there existed overhead gantries with sufficient depth or capacity underneath for holding a quantity ranging from 30,000 to 40,000 tons of materials for the furnaces, it was highly necessary that such a wagon should be made with a bunker bottom, so as to discharge its contents below, without the excessive manual labour at present required. Looking at the larger wagons from the freighter's point of view, he was of opinion that they would be very beneficial.

Mr. Edward H. Carbutt, Past-President, hoped that those members of the Institution who were at the present time visiting America were making it their business to enquire into the conduct of railway traffic, and the reason why it was there conducted so cheaply. To his mind it was lamentable that during the last two or three years the representations made by the public and by the railway authorities in the discussion before the Board of Trade in regard to railway rates had been so seriously conflicting. That discussion he believed had been a most expensive one, having cost a large amount of money not only to the government, but also to the freighters of the country, who had had to engage barristers to conduct their case. It had also cost the railways themselves a great deal, because during the whole time that the discussion was going on most of their general managers and most of their lawyers had to be in attendance; and the consequence had been that this portion of the talent of the country, instead of being directed to the saving of expense, had been largely engaged in incurring expense for the railways, which would have to be borne by the public in future. It would have been much better he thought if the large sum which the Board of Trade enquiry had cost had been spent in experiments to ascertain whether railway traffic could not be carried more cheaply than at present. If

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the public would bear in mind that they were partners with the railways, and if the railway companies would equally bear in mind that they were in partnership with the public, it would be possible to conduct their traffic much more cheaply than hitherto. A future date he hoped would witness much more extensive amalgamation of railway companies than had hitherto taken place, so that the railways would be in fewer hands than at the present time. A sliding scale would then be required, as in the case of gas works, so that when the railways paid a larger dividend they would be obliged to reduce their rates. The railways would then be directing their attention more and more towards conducting the traffic at a cheaper rate than they did at the present time.

The use of bogie trucks was simply a question of the exigencies of the traffic, as pointed out by Mr. Adams (page 492). The bogie trucks had been in use for some years under the long passenger carriages on the Midland Railway and other lines in this country, and their value was well known. The main feature of the long wagons described in the paper, as he understood, was that the sole-bars were made of tubes. But with regard to the extraordinary statements made as to the American mode of carrying traffic in contrast with the English mode, he for one should be loth to accept them as all perfectly true. The worst case in English practice appeared to be contrasted with the best in American. One of the reasons already alluded to (page 493) why traffic could be carried more cheaply in America was that their wagons had no outside buffers, thereby reducing the friction; but in England it was found necessary to have buffers. The English wagons involved a certain amount of friction; and if these long bogie-wagons were substituted, it would be found that the friction was still as great as at present, and greater than it would be if the shorter wagons had their wheels loose on the axles. His impression was that the time would come when it would be necessary to go in for wheels loose on the axles, so as to allow each wheel to revolve independently on its own account when going round a curve. Some years ago he had devoted a good deal of attention to this subject, and several wagons had been running on the Great Northern Railway for eight or nine years with the Miltimore

arrangement of wheels loose on their axles.* The principle of loose wheels he believed would be found to be the solution of the difficulty; but whether it was or not, he thought that, if the railways would spend some of their money in helping this Institution to carry out certain experiments with regard to traction, it would be a great advantage to the country at large; for a great many more experiments than had at present been tried were needed to settle such questions.

But he doubted whether the English railways would go in for longer wagons. Taking the case of the coal traffic into London, great difficulties would be experienced with longer wagons, because the present short wagons were obliged to be employed for shunting into the different drops, and for the different kinds of coal. Moreover,

* The Miltimore axle with loose wheels is shown in Plate 146. A pedestal block P carrying the weight of the vehicle is keyed upon each end of the plain cylindrical axle A, which is thus held from turning. Round the axle revolves a tubular wrought-iron sleeve S, on which is fixed at each end a cast-iron socket C; and inside each socket is fitted a cylindrical brass bush B, fitting the axle A, round which it revolves, while the sleeve itself nowhere touches the axle. The outside of the cast-iron socket C is turned to form the wheel seat, on which the wheel hub W is mounted loose, being held in place on the inside by the shoulder of the socket, and on the outside by a nut I screwed on the end of the socket and fitting into a recess turned in the hub. The bearing is lubricated with oil or grease from a chamber M in the pedestal block P, through a central longitudinal passage in the axle and down through a vertical passage to the bearing surface, which in this construction is on the under side of the axle. The outside of the brass bush B fits into the socket C with a surface rounded spherically, so as to allow a very slight oscillation in any direction, for enabling the bush to conform freely to the spring of the axle, thereby ensuring a perfect bearing throughout the whole length of the bush, and preventing undue wear at its ends. When running on a straight line, the wheels though loose on the sleeve carry it round with them, owing to the greater friction between the wheel hub and its seat than between the bush and axle. But whenever from any cause one wheel has to run faster than the other, either wheel is free to slip round on its seat, independent of the other, and without interfering with the revolution of the sleeve round the axle. The wheel seat is lubricated through a slot cut longitudinally across the thread on which the nut I is screwed to the socket C; and from the oil leaving the outer end of the bush B an ample supply is carried by centrifugal motion over the inner face of the nut to the slot, and forced through it to the wheel seat.

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as already pointed out (page 494), it would be found that there was only a small amount of traffic between intermediate stations, while the number of stations to be served was great, owing to the thickly populated country; and the result was that there was never any such long heavy haulage here as there was in America. It had been stated (page 487) that corn could be brought from places a thousand miles inland in America, then over the sea, and delivered in London, cheaper than it could be delivered from Scotland. At the present moment however not a penny had to be paid for bringing corn from America, because the ship-owners were glad enough to bring it for nothing as ballast. It was difficult to find out all the truth as to the cost of carriage, and he was glad that the question had been opened up by the present paper; but his own impression was that the railways of this country would not find it to their advantage to adopt large wagons. Years ago the Great Western Railway had had much larger wagons than they now used, and they had found it to their advantage to make the change to the present smaller size. When they had larger wagons, it was not a paying line; but now that they had smaller wagons, suitable for the traffic, they were paying much larger dividends than before.

Mr. Edward Jackson said that, although as a rolling-stock manufacturer he should be happy to make any wagons which the railways might decide to adopt, yet he saw many difficulties, such as had already been pointed out, in the way of working the traffic in England with these large wagons, which would be awkward to deal with in the conveyance of coal and minerals, wherever they had to be unloaded quickly. The first cost of such wagons he imagined would be little, compared with the cost of renewing the material from time to time. The question was one for the railways rather than for the wagon builders.

Mr. J. H. Watson, regarding the question from a commercial and economical point of view, had endeavoured twenty-five years ago to show how the railways could carry the greatest paying weight in proportion to the dead weight. An important step in this direction

had been taken on the Midland Railway in 1874, when the number of classes in passenger trains was reduced from three to two, whereby a great saving had been effected. Being himself a large contributor to the traffic of the railways in this country by sending goods over their lines, he strongly objected to paying double rates in England if the same service could be done for half the money, as it was in America. Although he had never been in America, he knew that on the canals there was a good deal of competition with the railways, and that formerly minerals and similar traffic used to be carried by water, but now with these long and improved cars the railways had obtained the traffic and beaten the water-carriage, being able to do the work cheaper in consequence of their paying weight being so largely increased. The question of railway rates was indeed a most serious one for this country, especially for manufacturers, merchants, farmers, and consumers; because, if the present high rates were kept up, they would drive the trade out of England for the benefit of foreign rivals.

Mr. James Colquhoun, general manager of the Tredegar Iron Coal and Steel Works, said this subject was a most interesting one to all who were connected with South Wales. With their present rolling stock the adoption of the long American wagons would involve expensive alterations. The first consideration was the saving in carrying a load of 30 tons in a truck weighing only 10 tons, as compared with carrying 10 tons load in a truck weighing 5 tons. No doubt the expense would be great of altering the sidings, turntables, weighing machines, hydraulic lifts, and many other existing appliances, to suit the longer wagons; but if it could be proved that their use would effect a largely remunerative saving over the present short wagons, the matter was certainly worthy of serious consideration.

Mr. G. E. Church mentioned that there were some six thousand of these tube-frame cars now in active employment in the United States, and many more were being built; the builders had more orders than they could fulfil without employing other works, and

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did not now build them except for leasing to the various railways, because they found this the more profitable method. With regard to the bogie truck, it had been stated by Mr. Adams (page 492) that a four-wheeled wagon with rigid wheel-base would take the load over a line as easily as a bogie truck. But if in a landau or brougham the forward wheels were rigidly fastened so that they could not swivel, and an attempt were then made to turn a corner at the rate of eight miles an hour, the difference between a bogie and a rigid wheel-base would be appreciated. Having himself sent five of the tube-frame cars to a railway in the Argentine Republic, he considered their carrying capacity quite secondary to their remarkable elasticity, which enabled them to take up and distribute every motion with the least shock, and consequently with the least wear and tear to the vehicles themselves and to the track on which they ran.

Mr. C. W. Rausch gathered from the paper that one of the merits of the tube-frame bogie wagon was the facility with which it could be repaired or rebuilt after it had been thrown off the line. This might constitute a merit on American railways; but on English railways accidents were so much more exceptional, that facility of re-building a wagon after it had been thrown off the line was not regarded as any merit at all.

Mr. J. J. Smith was surprised to hear Mr. Carbutt say (page 498) that the Great Western Railway had found it to their interest to reduce the size of their wagons. Having been interested as a freighter on that railway for the last twenty-five years, he was not aware that, apart from the conversion of broad gauge to narrow gauge, the tonnage of the wagons had been reduced.

Mr. Joseph Sanders considered that the prosperity of the country largely depended upon cheaper railway rates. By means of these tube-frame wagons the paper had shown that the American railways could carry twice as much load in proportion to the dead weight, for a 9-ton car could carry a load of 30 tons. In order to prevent skidding in running round curves, it had been proposed (page 496)

to have loose wheels. Instead of these however, he had himself devised a plan of dividing the axle in the middle of its length, and providing a centre bearing for the inner ends of the two half lengths, so that the wheels while still fixed on the axle could nevertheless run quite independently of each other when going round a curve, and all torsional strain upon the axles was done away with. In this way he believed the friction of the rolling stock would be reduced to much below what it was at present in the absence of any such provision.

Mr. J. C. Taite mentioned that at the Leeds Forge a considerable amount of attention had been given to the subject of reducing the dead weight of railway wagons; and he thought it was quite possible that this object could be accomplished by means of steel underframes shaped by hydraulic pressure, without the necessity for adopting the long wagons described in the paper, which appeared to offer so many difficulties for English railways. The pressed-steel frames gave an economy of 30 per cent. in weight, as compared with the replaced parts of a wooden underframe to carry the same load; and of 20 per cent., as compared with the lightest form of channel-iron underframe used on English railways. For the London and South Western Railway a large number of bogies had been constructed with pressed-steel frames. Little had as yet been done in England with these bogies for wagons, but they had been used more for carriages. For foreign railways a large number had already been made; and if the diamond bogie was as great a success in America as it was represented to be, it might be pointed out that with the pressed-steel frames a bogie could be made quite as light and quite as strong, and even cheaper. In a short period he did not doubt that wagons manufactured by English makers would be running on the lines in this country, not only of a lighter build but also carrying a heavier load than at present.

Mr. William Marriott said it appeared to be thought that nothing had been done on English railways with regard to reducing the dead weight of wagons; but he knew as a fact, although it had

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not been mentioned, that several of the new wagons described in the paper were now being tried in England. The chairman of the Eastern and Midlands Railway, who was also interested in a railway which carried in bulk—and after all the question was mainly one of carriage in bulk—had thought he should like to order half-a-dozen of the long tube-frame wagons for a trial. The traffic to be delivered was China clay in 30-ton lots. A difficulty however was experienced. The line of railway ran parallel to the shipping quay, and the present short trucks laden with clay were turned on small turntables to run down on to the piers into deep water. The long trucks would have been ordered, but for that difficulty. The turntables and the quay belonged to another railway, over which he had no control. That was an instance showing the difficulties with which the railways were beset. He had himself been much interested in this subject for a long time; but the Eastern and Midlands Railway, which he represented, was only a short line, and did not carry traffic in bulk. He agreed with Mr. Dawson (page 494) that a 2-ton load was perhaps the maximum, except in the case of coal and grain. At any rate it might be taken that coal and grain were the only two articles carried in sufficient bulk to render a long wagon like that described in the paper at all economical. He had himself been obliged to reduce the size of his wagons as much as possible, in order to reduce their dead weight. A great deal of the traffic was from other railways, whose wagons were consequently employed for it; but the local agricultural traffic was nearly all in light loads. The size of wagon to be adopted depended largely upon what was the bulk in which the traffic could be carried. In England nothing like the bulk was carried that was carried in America. Perhaps almost the only things that could be carried in bulk in this country were coal, iron ore, limestone, and grain. Reference had been made to the alterations of weigh-bridges, hydraulic stations, lifts, and turntables, which would be requisite if long wagons were adopted. In America, where there was plenty of land to be had for the purpose, triangles could be used instead of turntables; but in England as a rule there was not land enough to be got, and therefore turntables had to be put in so as to avoid triangles.

Mr. L. Sterne observed that the discussion had thus far turned altogether upon the use of bogies and the length of the wagons, and not at all upon the construction of the tube-frames, for which he noticed that iron tubes were employed. As already mentioned (page 501), Mr. Samson Fox had turned his attention to hydraulic forging as a means of making steel underframes for railway wagons. In this direction he had already done good work; and he believed he was now domesticating his method in America. But he was not making steel frames of such length as the long tube-frames described in the paper. Those tube-frames he thought might be made shorter to suit the length of the ordinary four-wheeled wagons. There was no reason that he could see why the tube-frame wagons should not be made as short as the ordinary four-wheeled wagons in use in Great Britain; and there was no mechanical difficulty that he could see to prevent this being done. Why the inventors should increase their difficulties by endeavouring to introduce tube-frame wagons of so much greater length than in use here he could not understand. If railway engineers and superintendents could see their way to reduce expenses in first cost or in maintenance, he was sure the advocates of the tube-frame construction would be listened to. During his own experience for the last twenty-six years he had always met with an attentive hearing in reference to any means of reducing the cost of maintenance, as well as of effecting a saving in first cost.

Mr. Henry Sandham wished to express his concurrence with Mr. Sterne's view, as he failed to understand why the same tube-frame construction should not be tried for the present short four-wheeled wagons, so as to meet the wants of English railways, and to try how far the light tube-frames would prove successful for lightening the dead weight and at the same time increasing the carrying capacity of the short wagons now in use.

Mr. Henry J. Marten, through whom the paper had been communicated, was satisfied that the present discussion of the subject would be found eventually to bear fruit and to produce good results in connection with the English system of carriage of goods by

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railway, more especially of those known as the mineral class. Although his own connection was principally with water carriage, and it would not therefore seem to be altogether to his immediate interest to advocate the introduction of anything that would materially lessen the cost of railway carriage in competition with water, yet he was convinced that, if a saving could be effected in the cost of carriage, such saving, in whichever way made, whether by water or by rail, would eventually react favourably upon the other mode of carriage. There could be no doubt that, the cheaper the carriage of goods could be made in England, especially of the heavy raw description he had already alluded to, the longer would this country be able to maintain its commercial position.

Mr. T. Hurry Riches, Member of Council, considered the paper was highly interesting to railway engineers, who were all trying to progress with the times. Reference had already been made to the introduction of pressed-steel underframes (page 501), as a means of diminishing the dead weight of railway wagons; and also to the reduction of tare in the Great Western Railway wagons (page 498). The latter he knew to be a fact; for their former 8-ton narrow-gauge wagons had been reduced to 3·80 and 3·25 tons tare since they had been constructed with iron and steel frames and bodies, instead of with oak or other wood bodies. As far as long bogie-wagons were concerned, notwithstanding their advantages, there were several grave objections to them for English railways. Their advantages appeared to him to be fairly good for carrying rails or clay or heavy traffic of that kind in bulk. But then, coming to the coal traffic, there were few districts in England where it was not wanted to tip the coal wagons for shipment; and he failed to see how such a long wagon as that described in the paper was going to be tipped with anything like reasonable dispatch, and without entailing upon the docks and railways an enormous expenditure in the alteration of their tips and other appliances. The expenditure might indeed be a small item relatively to the prospective economy of the change; but he was sure it was a serious consideration, and it must be faced before any rash experiment was adopted in placing a large number of these long

wagons upon English railways. With regard to other goods traffic, it had already been mentioned by Mr. Dawson (page 494) that a large percentage of it was carried in light parcels, or at any rate in small parcels. A large proportion of truck loads of goods in England he believed did not exceed 2½ tons. If indeed it were possible so to collect and classify the goods traffic as to be able to load the long wagons fully, and hence take advantage of their decreased tare, he could quite understand that it would be a great advantage to the English railways; but when goods had to be sent in small lots in different directions and over branch lines, he thought the longer wagons, instead of reducing the dead weight, would materially increase it. Therefore, unless for special traffic, he failed to see where their advantage came in for the railways in this country.

As to the tube-framing of the wagons, he had himself had some experience of tube-frames for some special trucks, and he had always found it a difficult matter to get them to hold rigidly together. In a short period after they had been put together, and even when he had welded them, or put flanges on the ends and bolted them up somewhat in the way shown in the drawings illustrating the paper, they appeared gradually to work loose and become like an old umbrella. There was a good deal too much freedom about them, too much elasticity and play in the parts; and with the heavy and fast traffic in England he was sure the railways could not afford to run the risk of serious accidents through having anything other than a thoroughly rigid frame and body for their wagons. Like Mr. Sterne (page 503), he should have been glad to have some definite information given as to the use of the tube-frames in the ordinary short wagons of standard length. He did not himself see why the tube-frame should not be adapted and adopted for the short wagons, whereby something might be economised in the tare. But some of the statements made in the paper were hardly in accord with English practice. The tare of an 8-ton wagon was given (page 485) as 6 tons, and of a 12-ton wagon (page 488) as 10 tons. Now the tare of a large percentage of English wagons was only 5¼ tons for a 10-ton load. On the North Eastern Railway there were many instances of 6 tons tare for 10 tons load, but in South Wales the tare rarely exceeded 5¼ tons for that

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load. The advantages gained therefore were not of the magnitude claimed in the paper. There was certainly one point that was worthy the careful consideration and experiment of English engineers, namely the use of the chilled cast-iron wheels. For mineral and other slow traffic he thought these wheels might be beneficially adapted to the present rolling stock, with a reduction of course in the tare, but not a large reduction.

With reference to the bogies, he failed to see why in a bogie truck there should be any less skidding of the inside wheels in going round a curve than in an ordinary four-wheel wagon; for after all the bogie truck was only a shorter four-wheel wagon. At the same time, wherever a long wheel-base was used, there was no doubt an advantage accruing from the flexibility of the bogie. He had himself had a great number of bogies running under engines; and he might mention one experiment which had shown him the advantage of a bogie on a long wheel-base. Some of his engines had six wheels coupled and 14 ft. 8 ins. wheel-base, and were 32 tons weight. He took out the trailing wheels, did away with the tender, and put a bogie under the trailing end, giving the engine 1,100 gallons of water to carry: which altogether added something like 12 tons to its weight. By doing away with the tender he saved 16 tons; but up the ordinary gradient of 1 in 200 the same engine succeeded in taking 8 per cent. more load with the same steam-pressure, and with the adhesion of four wheels instead of six. That was an illustration showing the advantage of a flexible wheel-base upon any road. As to bogies under carriages, the present practice was to give more accommodation, larger air-space, and so on, for the passengers; and this was not accomplished without a material increase in the dead weight carried. A carriage for seventy persons now weighed 16 or 16½ tons, whereas formerly a carriage for fifty persons weighed less than 10 tons. As far as passenger traffic was concerned, the railways were really compelled to increase the dead weight or non-paying load. As to mineral traffic he hoped it would be possible to get some further information about the flexible tube-frames, so as to see whether anything could be saved in the weight of the present wagons. It this could be accomplished, it seemed that the use of a longer wagon

was not at all applicable to the general traffic of English lines; and if a long wagon was not required, equally a bogie was not required. The matter resolved itself he thought into the question of a short wagon, something similar to the present, and of the smallest possible tare, which might be still further reduced by using chilled cast-iron wheels.

The President said that letters had been received from four gentlemen who were unable to be present, which it might be well to read at this stage of the discussion.

Sir James Ramsden, Vice-President, wrote that the tube-frame wagons had been running on the Furness Railway for nearly two years. They had been in constant use, carrying traffic from the steel works to the docks, their regular load being 30 tons, while the tare of the wagon was only 8·3 tons. The repairs to them had been practically nil; and they had given him such satisfaction that he had ordered a further number.

Mr. R. H. Twelvetrees, chief goods manager of the Great Northern Railway, wrote that one of the 30-ton tube-frame wagons had been in use on that railway for the past six or eight weeks. It was first put to use between the ironstone pits at Caythorpe near Grantham, and the West Yorkshire Iron and Coal Co.'s furnaces at Ardsley near Leeds. The tare of the wagon itself was $8\frac{1}{2}$ tons; and on weighing five of its net loads they were found to range from 20·6 to 30 tons; the tare thus ranged from 29 to 22 per cent. of the gross weight. By way of comparison 278 Great Northern Railway wagons running between the same places had also been weighed, with the following results:—average tare 5·2 tons; average net load 8·6 tons; tare in percentage of gross weight 38 per cent. The report as to the running of the tube-frame wagon was everything that could be desired; and the deflection in the centre ranged from 1 inch to $1\frac{1}{4}$ inch. One journey had also been made from Poplar, London, to Cambridge, with a net load of $24\frac{1}{2}$ tons of grain, the tare being then $25\frac{3}{4}$ per cent. of the gross weight. The wagon had fixed sides

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15 inches high, and was therefore inconvenient for general traffic; the fixed sides also entailed a good deal of extra expense in loading and unloading the ironstone, but this he hoped would be obviated when the sides were made higher and doors provided. It was now in the possession of the author of the paper, in order that it might be fitted with sides about 3½ feet high, with two let-down doors on each side; after it had been received again so altered it could be tested with traffic of a more general character.

Mr. J. W. Johnstone, locomotive engineer of the Cork and Bandon Railway, wrote that he had endeavoured to get some of the tube-frame wagons on that line, but some of the bridges were not up to their weight. The traffic department were not at all in favour of these wagons, chiefly on account of the difficulty in handling them, and because of not being able to get sufficient load for most stations for one wagon.

Mr. J. F. Mostyn Clarke, of the Mannesmann Tube Works, Landore, wrote that in these days of mild steel it seemed surprising wrought-iron had been chosen as the material for construction, especially in those portions where tubes were used. In the case of welded tubes no doubt wrought-iron was more reliable than steel; but with the numerous processes by which weldless steel tubes of small size were now made, it seemed to him that greater advantages might accrue from the use of steel tubes, considering the reduction of section that would be possible. The first cost would perhaps be greater; but this would be well balanced by greater carrying power and durability, with the same or slightly smaller sectional area. For an example might be taken the comparison between a wrought-iron welded tube and a steel weldless tube, which had been given in a paper lately read before the Society of Arts (Journal 23 May 1890, pages 651–2) by Mr. J. G. Gordon upon the Mannesmann process of rolling weldless steel tubes. There a marked difference was manifest between the strength and behaviour of the two. A steel tube about 3¼ inches outside diameter and about 1-8th of an inch thick bore a longitudinal compression load of 35 tons

per square inch of metal, without a fracture of any kind appearing in the tube wall, which was much bent up; while a wrought-iron tube of the same thickness but $3\frac{3}{4}$ inches outside diameter stood a compression of only 21 tons per square inch, under which the fibres of the iron opened in the bends at intervals, parallel to the axis of the tube.

It was interesting to know that the tubes used in the wagons now described had given such satisfactory results in practice in the positions assigned to them; and as far as railway rolling stock was concerned, the tube-frame construction appeared to him to be decidedly a step in the right direction; for it was clear, as pointed out in the paper, that the present European mode of construction might be improved. There seemed also to be some tendency among engineers to use tubes more freely in general construction; and having himself recently been considering a truss in which tubes might be used for both compression and tension members on a large scale, he should like to ask the author for any information he could give as to the use of steel tubes, instead of the wrought-iron tubes described in the paper.

Mr. J. L. Wilkinson, chief goods manager of the Great Western Railway, said the first thing that struck him in connection with the paper was the seeming assumption therein that the bogie truck was new to England. That was not quite the case. There were traces of the bogie principle in work on the Great Western Railway nearly fifty years ago; and the idea he believed had been transported from England to America.

The traffic moved on the railways in England was different in character from that in the United States, where the distances were greater and the loads heavier. Practically it might be said that in England there was more of a retail than of a wholesale business. General merchandise was usually carried in small lots, and started on one of the main lines, off which ran branch lines, and off those branch lines again there were other branch lines: so that it was difficult to make up big loads for bogie wagons. The tonnage on the railways of the United States exceeded he believed the total tonnage

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on the European continent, and was moved in large consignments upon fairly level lines; and it was patent to everybody that in this country there were not only the small lots, the short hauls, and the cross-country train services, but there was also a great deal of up and down hill work, and comparatively little level road, which were important factors in considering the question. Then the style of doing business was different. English traders, whether in London, Manchester, or elsewhere, always expected that any goods consigned to a railway in the afternoon should reach their destination the next morning; and the railways laid themselves out to fulfil this expectation. That was not the case in North America.

As to the difficulty of getting a full load, it had been stated only recently by Mr. Findlay, of the London and North Western Railway, that the average load per wagon which they were able to get of general merchandise on that railway was under two tons. Recently too he had himself taken the opportunity of testing the loading on the Great Western Railway; and he had found that they were not able to get more than an average of $2\frac{1}{2}$ tons for the week during which the test was made. It followed that in ordinary circumstances the usual 10-ton wagon was more than sufficient for the traffic. Having had to manage formerly a railway in South America, he had had some experience there in the working of long bogie wagons; and subsequently in this country he had tested the experience gained upon the other side of the Atlantic, having arranged with Mr. Dean for a general goods wagon to be built of the standard North American type, and to be put to work in the most favourable conditions possible on the Great Western Railway. The results of that experiment were closely pertinent to the present enquiry. After a great deal of trouble, and trying the wagon in different parts of the country on the Great Western system of nearly 2,500 miles, he had found it was impossible to get anything like a full load of general merchandise, except between two pairs of stations, namely between London and Birmingham, and between London and Bristol. Nowhere else was it possible to get a full load in both directions. On totalling up the results of 204 journeys made by that wagon during the past twelve months, he had found that the average load carried between those

particular pairs of stations was only 7·35 tons. The maximum load that he was able to get was 12·35 tons. Hence on many occasions all the traffic could have been easily carried in a 10-ton wagon of the English type; and in the few cases where it could not be so carried, it could have been taken in two such wagons. As a matter of capital cost it was seen from the information given in the paper (page 489) that two wagons of the English type could be provided at a less cost than one of the North American. In that direction therefore no advantage was offered, so far as he had been able to ascertain. It was well known that many bogie wagons had long been in use on the English railways. The wagons used for carrying boilers, masts, and other heavy loads of great length, had been of the bogie type; and if more traffic could be got, such as would justify the use of bogie wagons, the railways would be glad to use them more.

Another point was that there were obligations laid upon railways in England, which were not thrown upon those in the United States. The English railways had to comply with certain government obligations, under which it was the practice to give a greater strength to the wagons than was given to the American, so far as could be gleaned from the information already furnished. It was well known that the standard English wagon, which was marked as carrying 10 tons with a tare of about 4·85 tons, had really as much as half the carrying capacity of the long American wagon, although the latter was said to be capable of carrying 30 tons. It would therefore be seen that the English wagon might, under the same conditions, be fairly marked to carry more than its present load of 10 tons, if the same elements were to reign in its construction.

It had already been pointed out how an increase in the length of wagon would necessitate changes in turntables and hydraulic hoists, such as existed especially in London and other large towns; and also in coal-tips, coal-drops, weighing machines, and cranes. With regard to turntables, a suggestion to be inferred from the paper (page 488) was that they might possibly be dispensed with, and be replaced by triangles; but that was scarcely a practical suggestion, because, although the use of a triangle would enable an engine or a wagon to be turned the other way round, it did not put the wagon in the

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place where it was wanted, which a turntable enabled to be done. In addition to this, there was a difficulty in large towns in sparing land enough for laying out triangles (page 502); having constructed some himself, he was able to appreciate this aspect of the question. Another difficulty would be in moving the long wagons about by horses in station yards. A bogie wagon with a tare of 10 tons and carrying 25 or 30 tons load would be more than could easily be handled, especially if the gradient was a little against it. There was also a difficulty which had not been mentioned in connection with the use of the long heavy wagons intermingled with the existing shorter wagons, namely that, according to the present construction of the long wagons, there was a danger of the buffers getting locked with those of the short wagons; but he was aware that this was a difficulty which could be easily obviated. When one of these bogie wagons got off the road, he knew from painful experience that it was uncommonly hard to get it on again; it was so difficult to handle it when it got off the line, especially on a soft road. Moreover as there were some fifty millions of money invested or spent in England in the manufacture of the English wagons, it would be a rather serious thing to change their construction, apart altogether from changing the tips and other appliances. And in regard to heavy traffic in bulk, like coal and iron ore, the latter was often sent, both in North America and in England, in smaller wagons specially constructed for the purpose, from which the bottoms could be removed, or traps opened, to allow the ore to descend from a higher to a lower level. In that respect he presumed there would be a little difficulty with the long bogie wagons; and even if the opening were made in the bottom of the wagon, shovelling would also be necessary, or some means of getting the contents to the opening. Beyond the fact already stated that bogie wagons were not altogether unknown in England, it could further be said that there was not a wagon works of any importance in this country which did not constantly make bogie wagons to send to the colonies and elsewhere. The method of making them was well understood; and he hoped that whatever form was the best would be adopted in England.

Mr. William Dean said that, although he had never yet had the pleasure of visiting America, he had seen one of these tube-frame bogie wagons when first exhibited in London in August 1888, and had ever since taken a great deal of interest in them; and he certainly regarded their construction as clever and ingenious. At the same time they were built in such a way as to be adapted more especially for American than for English traffic. It would be observed that the buffers were placed much nearer the centre of the wagon, so as to come in line with the two inside longitudinals. This rendered it unnecessary, he presumed, to provide any diagonal bracing, which he thought would be essential in the case of wagons fitted with buffers placed according to the English standard, 5 ft. 8½ ins. apart from centre to centre; and especially would such diagonal bracing be necessary in the case of wagons used on lines with severe curves.

But after all, the business of carrying heavy loads was still somewhat in its infancy, even in America; and he might therefore refer to a few expressions of opinion which he had met with in American publications relating to this subject. According to the Report of the sixteenth annual convention of the Master Car Builders' Association in June 1882, during the discussion upon the report of the committee on the carrying capacity of freight cars, Mr. C. A. Smith said (page 58), in answer to an enquiry about putting 30 tons into the cars, "Into how many cars can you put 30 tons of freight? that is, of certain classes of freight? You can just as well put that freight into large cars as you can into small ones. Of course we understand with the 30-ton car that it is only when that class of freight which we now put into the ordinary cars is used that it will have that capacity; and I will say again, how many cars have been built in former times to carry 10 tons, to which all that has been done to make them carry from 15 to 20 tons has been to alter the figure on each side, and they would carry the increased load safely? Your cars that were 10 tons capacity are now carrying 20 tons, and carrying it safely; and all it took was a painter to change the capacity from 20,000 lbs. to 40,000 lbs." That quotation might to some extent account for part of the progress which had been heard of as taking place in the reduction of freight expenses in America. In the

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report of a subsequent meeting of the same association in 1889 he had also found the same subject touched upon by Mr. Rogers, railroad commissioner of the State of New York, who said (page 7), "It seems to me—I am an engineer myself—that the limit is getting pretty rapidly reached with the loads you propose to put on your cars. When you get 60,000 lbs. on your car, the effect that it has upon the rails and upon the road-bed, and upon the ties, and above all upon the bridges, is a pretty serious thing, particularly at the high rates of speed at which these heavy loads are now being transported; and it seems to me that the time has come when you should consider whether the limit of these very heavy loads has not been pretty nearly reached. If you go on making them any heavier, it seems to me you will have entirely to reorganize your road, and build it on a different basis." It should be observed that 60,000 lbs. was equivalent to not quite 27 English tons: so that a 30-ton car in America meant really a 27-ton car in England.

That the subject was still comparatively young in America was proved by the fact that only so lately as September 1889—little more than a year ago—had the Master Car Builders' Association (Report June 1889, pages 87–109 and 211, and plate viii) settled a standard axle for cars of 60,000 lbs. capacity. This showed that the experience of running such heavy loads had not as yet been fully developed.

Then with regard to chilled-tire cast-iron wheels, there could be no doubt that a considerable fraction of the saving in tare must be put down to the credit of those wheels. Taking the standard axle just mentioned, and fitting it with a pair of 33-inch chilled wheels, as compared with the axle and the 36-inch wheels with steel tires that were generally in use in this country, there would be a saving of probably about $2\frac{1}{2}$ cwts. on the pair of wheels and axle, making a saving of 10 cwts. altogether in the two bogie trucks of the long wagon, which of course was a consideration not without its attraction. But chilled wheels, as far as he knew, had never found favour in this country. On this subject he found in the report of a meeting of the American Railway Master Mechanics' Association in June 1888, in the discussion upon the report of a committee on cast-iron wheels,

that Mr. J. N. Lauder stated (page 155), as one of the committee who had agreed to the report :—"There are some railroads that will not trade with a firm or a concern that is known to dabble in poor wheels. They only trade with those well-known firms whom years of experience have proved [to] make a good wheel, and whose business standing will be a guarantee that they will not make a poor wheel. But I am sorry to say that the number of roads which take that view are largely in the minority, and the consequence is that the chilled car-wheel is deteriorating to [such] an extent that the roads at the present time are obliged to use other wheels, solely on account of the danger attending the use of chilled wheels. . . . . Something has got to be done to stop the use, and the manufacture if possible, of these poor chilled wheels." In September 1889 the Master Car Builders' Association (Report June 1889) had adopted a specification (page 203), in which the maker of the wheel was required to give a guarantee that in certain cases he would incur a charge for a defective wheel. An exception in his favour was made in the case of wheels removed for causes enumerated (page 205), of which the two following struck him as important :—"Chipped flange ; broken flange, if the breakage is not caused by seams, worn through chill or worn flange." The liability to such defects as these had always seemed to him to be a somewhat serious risk in connection with the use of chilled wheels ; and as the engineers in America were speaking of their increasing speeds and increasing loads, the question suggested itself whether the troubles they were experiencing were not rather due to these causes than to a deterioration in the manufacture of the wheels themselves. He also observed a statement in the "Engineering News and American Railway Journal" of 14th June in the present year (page 553) that "On June 6th the north western passenger train from Freeport to Chicago was derailed by a broken wheel near Rockford, Illinois. The train ran about 200 feet and then toppled over, wrecking the entire train, and killing the engineer and four trainmen, and injuring two section men and several passengers." Of course that might be an exceptional occurrence ; but not having full access to all the statistics of American practice, these items which had come under his notice were such as to cause him to think

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seriously before he could accept the responsibility of putting the chilled wheels to work upon an English railway. (See page 527.)

Mr. John C. Calhoun, Vice-President of the Central Railroad and Banking Company of Georgia, said the question of transport had lately come before the executive committee, of which he was one, having the management of about 9,000 miles of railway in the southern portion of the United States, comprising the East Tennessee Virginia and Georgia and the Richmond Danville and West Point Railways, together with the old lines of the Central Railroad and Banking Company of Georgia. The executive committee had appointed three eminent engineers to give them the advantages of all modern facilities for transport. Since the war of twenty-five years ago the American cotton crop had increased from three million bales a year to seven million bales, which had greatly increased the tonnage over those railways. Moreover, whereas ten years ago the production of pig iron was scarcely known in the southern states, the tonnage now produced was eight times as great as that of the entire cotton crop, which had previously been the principal industry of the country. It had therefore become a matter of great importance to avail themselves of the cheapest method of transport.

The Central Railroad and Banking Company of Georgia was one of the oldest of the American railway companies. The first railroad in America was the South Carolina, which ran between Augusta (Georgia) and Charleston. The next was that of the Central Railroad and Banking Company, Georgia, which however was entirely destroyed after the war, during the march of General Sherman through Georgia. The iron rails were heated and lapped round trees, and nothing but the bare road was left. The track was relaid as speedily as possible with the old iron rails, which were beaten out straight. At that time the heaviest locomotive weighed only 20 tons. It had since been found necessary, on account of the heavier traffic, to replace the original rails weighing 56 lbs. per yard with 60-lb. and afterwards with 70-lb. rails, which latter were now the lightest that were laid on those railways. The engines had also been increased from 25 tons up to the six-wheeled engines of the Baldwin

make, weighing 90,000 lbs. These had involved improving the road bed throughout, and strengthening the bridges: all of which had cost a great deal of expense. With a view to the easiest method of transporting their heavy traffic, they had sought out the lightest cars having the greatest strength, so that one engine should be able to haul the largest amount of tonnage. The car they had adopted as the lightest and the most available was the tube-frame bogie car described in the paper. There were now four hundred of these cars on their lines, and they had decided to adhere to this construction for the future. The tonnage having so greatly increased, it was necessary with such long distances of haulage to make one engine haul as much as possible; for if on the long single-track lines in America one train had to be sent out behind another, it would seriously interfere with the traffic. With the Baldwin locomotive and the tube-frame car the engineers reported that it was found a greater tonnage could be hauled by one engine than on any other plan that had been tried.

Mr. W. A. Adams observed that, if the present standard English wagon to carry 10 tons could not get average loads of more than $2\frac{1}{2}$ tons ordinarily up to $7\frac{1}{2}$ tons on exceptional routes, as mentioned by Mr. Wilkinson (page 510), it seemed natural to ask what need there was that it should be built to carry a maximum of 10 tons with a tare so high as 4·85 tons and upwards.

Mr. Jefferds considered there was room for a saving of 67 per cent. to be effected in the working expenses of the railways in this country; and only 9 per cent. of that saving was to be attributed to the saving in tare by the use of the tube-frame car itself, the balance being made up by the difference between the rigid wheel-base of the standard short wagons and the flexible wheel-base of the bogie wagons. The four-wheeled wagon with its wheels attached rigidly to the frame exerted a lateral pressure upon the rails; the flanges of the wheels were forced against the rails not merely by the momentum of the wagon itself but also by that of the load as well, whereby the violence of the

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shocks was greatly increased. With the bogie trucks 90 per cent. of the vibration was taken up without being imparted to the body of the car and its load. This saving of shocks he was satisfied would cover the greater part of the expenses incurred in maintenance of permanent way and in repairs and renewals of wagons.

On the 9,000 miles of railway in Georgia, mentioned by Mr. Calhoun (page 516), running through a country which only twenty-five years ago was devastated by war, there were now fewer miles distance between the stations than on the Great Western Railway; and there was not a four-wheeled wagon on the entire system. There were many towns to which they delivered less than six tons of goods in the whole year; yet the traffic was all conducted in the long bogie-wagons. On a canal serving a number of towns no one would think of allotting to every customer who wanted to send $2\frac{1}{2}$ tons of goods a separate boat all to himself. The principle applying to the long bogie-wagons was the same that had led up to ocean-going ships which would carry 10,000 tons. That was the way to reduce the rates; and only today he had received an offer of freights from New York to Liverpool at 15*s.* a ton, instead of £1 as for months past.

As to the suggestion of adapting the tube-frame construction to the existing short wagons (page 503), he regarded the principle of the short four-wheeled wagon as wrong in every way. What could be done with a four-wheeled street van, if built on the same principle as the wagons on English railways? If it wanted to turn a corner, it would have to be lifted round; and that was what had to be done with the wagons on railways, and it was that which required so much power. Every wagon in a train going round a curve was trying to run at a tangent, and therefore required extra power to haul it round the curve. However extraordinary it might seem (page 493), the power required to haul 32 of the short four-wheeled wagons loaded with 8 tons each was really sufficient to move as easily 40 of the long bogie wagons loaded with 30 tons each, with much less wear and tear to the permanent way and to the vehicle.

With regard to the unloading of coal from the long wagons, a photograph was shown in Plate 144 of one of the long wagons built for loads of 30 tons and in some cases 40 tons of coal, which was

discharged within 1½ minutes through the hopper bottom of the wagon. The average load of 2½ tons of general merchandise per wagon, mentioned by Mr. Wilkinson (page 510) as obtained on the Great Western Railway, had reference to only 25 per cent. of the traffic of that line, 75 per cent. being minerals which were carried in fully loaded wagons.

With reference to steel tubes (page 508), of which a trial had been made for the tube-frames of the long wagons, it had been found that, on straightening them after they had been subjected to a bend of short radius, a crystallization had taken place in the steel tubes, which weakened them seriously. The result was that the use of steel tubes had been abandoned for the present; and he did not think that by their use anything could be gained in reduction of weight. Perhaps the time might come when steel tubes might be used; but as long as iron tubes could be got at the cost at which they were now obtained, they would be preferred to steel tubes.

For the last two or three years he had been trying to procure in England the tubes and malleable castings and other parts, required for the cars which he had been sending to all parts of the world. The malleable castings supplied from America and used in this country had been tested for years, and never found wanting. They were delivered in London at 17*s.* 4*d.* per cwt., whereas the lowest quotation he had received in this country was 24*s.* No steel castings that he had seen would answer, on account of their being weakened by blow-holes. The tubes were got from Conshohocken, Pennsylvania, 33 feet 2 inches long, plugged and screwed at each end, 2½ inches inside diameter and 2⅞ inches outside; and were delivered in London at 28*s.* 6*d.* each, as against 32*s.* asked in Birmingham exclusive of the carriage to London. The grey-iron castings cost 7-8ths of a penny per lb.; but the lowest price in this country was 1½*d.* or 1¾*d.*

The bogie with pressed-steel frame, made by Mr. Samson Fox (page 501), was certainly a great improvement on the old square-framed truck previously used in the United States; but the square-framed bogie had been abandoned in the United States on account of its rigidity, and had been marked in the carbuilders' dictionary of 1884 as no longer in use. As to the pressed-steel frame being lighter,

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he did not know the weight of the bogie so constructed; but from the experience he had had with it he considered that, the parts being riveted together, it could not carry with safety so heavy a load as the bogie described in the paper, in which there were no rivets at all. The weight of the latter, complete with wheels and axles, was just under 2 tons, and the cost was about £20, the cost of the two trucks for the long wagon being about £40. The cost of the ordinary gondola car described in the paper was £150. The tube-frame of the car was what had cost so much time and trial to mature into the present success; the great difficulty had been to hold the tubes fast. The fastenings now used, as shown in the drawings, were made to hold the tubes as tight as if in a vice. The so-called 30-ton cars were really made to carry 32 gross tons; 32 tons was the regular limit of load for a speed of 40 miles an hour. The long car thus took the place of four of the old short wagons costing say £240 altogether, whereby a saving in cost was effected of from 30 to 40 per cent.

With the long wagons it had been objected (page 512) that no horses could be used for shunting in station yards. In America horses were not used in station yards, because it was not necessary, owing to the adoption of other devices whereby a boy could move one or more of the long cars loaded with 30 tons each.

Diagonal bracing, alluded to by Mr. Dean (page 513), had never been found necessary in the framing of these wagons, on account of the way in which the tubes were fastened together, the fastenings holding them as tightly as if in a vice. Not only had it never been found necessary to use any diagonal bracing in the tube-frames, but it was desirable to avoid its use, because it stiffened the wagon too much. One of the tube-frame wagons he should be happy to place at the disposal of any locomotive superintendent in this country, in order that he might load it with 30 tons and put it upon a curve, and back into it at the rate of ten or even twenty miles an hour with a train of loaded ordinary wagons; he was satisfied it would be found that it could not be so disabled thereby as to prevent its running a hundred miles with its load after the test.

With regard to the chilled wheels (page 514), there were now more than eight millions of them in use in the United States, and

perhaps not more than 100,000 of the steel-tire wrought-iron wheels such as were used on the railways in this country.

In regard to carrying traffic over long distances (page 498), it would be found on referring to the statistics of railways in the United States (issued by the Inter-State Commerce Commission for the year ending 30 June 1889, page 29) that the average distance over which one ton of freight was hauled on all the railways throughout the United States was only 127·36 miles. On the Pennsylvania Railway it was 135 miles, and the average charge was 42½ pence per ton. On the London and North Western Railway the average charge on all classes of freight was 42 pence per ton. Assuming the freight charge to be only one penny per ton per mile, the average distance through which a ton of freight would have been moved on the latter railway would be 42 miles. It seemed clear therefore that on the Pennsylvania Railway with the bogie-truck system the charge for moving freight 135 miles was practically the same as on the London and North Western Railway for only 42 miles.

From his own experience both in the United States and in England he failed to see wherein the traffic was different, except that in the former there was more retail business than wholesale. The conditions in the United States were somewhat different, namely:— first come, first served; immediate despatch of all freight received; immediate notice to consignee of arrival at destination; consignee must take goods within twenty-four hours from notification of arrival; no terminal charges whatever. All goods were received and delivered, loaded and unloaded, by the railway servants at the station platforms. If a car containing only 2½ tons were wanted by a trader to be left in a siding at its destination, he must pay the price for a car fully loaded with the same class of freight; and if it were not unloaded within twenty-four hours, a mileage rate was charged, equal to what the car could earn if running. The policy of the receiving department was to load all cars as full as possible, and of the delivery department to empty all loaded cars with the utmost despatch. Thus if any trader were extravagant enough to require a special car for a mere handful of goods, it had to be paid for by himself, and not as in England by the public generally.

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From page 50 of the railway returns of 1889 to the Board of Trade it would be found that the total tonnage of the Great Western Railway for 1888 was 25,944,703 tons, of which 19,653,714 tons were minerals and 6,290,989 tons were general merchandise; that is, 75¾ per cent. were minerals which were carried in full loads, and only 24¼ per cent. was general merchandise, of which the average load per wagon had been stated by Mr. Wilkinson (page 510) to be only 2½ tons. This general merchandise was what was termed in America retail or detail traffic. From page 51 of the same returns it would be seen that the receipts for minerals were £2,095,321, or 1*s.* 7½*d.* per ton; while those for general merchandise, including cattle, were £2,377,490, or 8*s.* 10½*d.* per ton. Assuming that the mileages of merchandise and of minerals were equal, the charge per ton for merchandise was 5½ times greater than for minerals; and this was just what was complained of by the traders, manufacturers, and farmers. The system of allotting a separate wagon to every one who had a ton or two of goods to send, and permitting him to use that wagon as a storehouse for an indefinite period, was most expensive; and when this was permitted, it should be paid for by the person so using the wagon, whereby the loss would be kept out of the general account. The average rate charged by the Great Western Railway for all classes of freight was at least 1·25*d.* per ton per mile.

From the report of the New York Central Railway for 1889 it appeared that their freight traffic was 70·35 per cent. general merchandise, and only 29·65 per cent. minerals, including pig and bar iron, and iron and steel rails. Hence the percentage of retail and detail traffic on that line was 2·9 times greater than that of the Great Western Railway. The main line of the New York Central Railway was only 441 miles long, and the average distance that one ton of freight was carried was 184 miles. The whole of this traffic was conducted in long bogie-truck cars at an average charge of 0·38*d.* per ton per mile. At the same time the wages paid were double of those on the Great Western Railway.

The following comparison of the working expenses on these two railways, without reference to the difference in wages, was calculated for the Great Western Railway from the railway returns for 1889 to

the Board of Trade (page 50), and for the New York Central Railway from their own report for the same year:—

Working Expenses per ton per mile.	Great Western. Penny.	New York Central. Penny.
Maintenance of way, works, &c.	0·1294	0·0411
Locomotive power (including stationary engines)	0·1611	0·0696
Repairs and renewals of carriages and wagons	0·0546	0·0264
Traffic expenses, coaching and merchandise	0·1766	0·0779
General charges	0·0235	0·0041
Rates and taxes	0·0333	0·0138
Government duty	0·0098	0·0001
Compensation for personal injury	0·0004	0·0019
Compensation for damages and loss of goods	0·0037	0·0010
Legal and parliamentary expenses	0·0041	0·0010
Steamboat, harbour, and canal expenses	0·0221	0·0126
Miscellaneous	0·0001	0·0079
Average Working Expenses per ton per mile	0·6187*d.*	0·2574*d.*
Average Charge per ton per mile for moving freight	1·25*d.*	0·38*d.*
Percentage of Working Expenses on Gross Receipts	49·50 p.c.	66·42 p.c.

It thus appeared that on the Great Western Railway using four-wheeled wagons the cost of working the traffic was not only 140 per cent. more than on the New York Central using nothing but long bogie-truck cars, but it was also actually 63 per cent. more than the charge made by the latter railway to their customers. Taking the first five items of the above working expenses as being those that would be affected by rolling stock, if the Great Western Railway had worked their traffic as cheaply as that of the New York Central Railway, their working expenses in 1888 would have been only £1,983,968, instead of the £4,193,109 that they actually amounted to; there would thus have been a saving of £2,209,141 in one year, which would have been sufficient to equip the entire line afresh with modern rolling stock, and to change the terminal appliances to correspond.

It was impossible in America, as it was in England, to load every wagon fully. From the report of the New York Central Railway it appeared that in 1889 the average number of wagons in each train was 37, while the average load carried per train-mile was 226 tons;

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therefore the average paying load of each wagon was only six tons. Hence it followed that only a small portion of the saving to be effected by the long tube-frame bogie-wagons could be attributed to the difference in the proportion of dead weight. It was the system that must be changed, in order to reap all the benefits of modern railway working. All American railways were equipped with long bogie-wagons. The average equipment and number of persons employed per hundred miles of road, as reported by the Inter-State Commerce Commission, were as follows, with English comparisons for some of the items:—

Per hundred miles of line.	American.	English.
Locomotives	19	80
Wagons in freight service	557	2,528
Carriages in passenger service	17	182
Ton-miles per freight locomotive	4,538,786	
Passenger-miles per passenger locomotive	1,430,105	
Persons employed	459	1,748

The President asked the Members to join him in passing a cordial vote of thanks to Mr. Jefferds for his paper; it had elicited from many points of view such an ample discussion as he hoped would eventually bear fruit.

Mr. C. P. Sandberg wrote that, in concluding his paper on steel rails at the recent Sheffield Meeting of this Institution, he had expressed the wish (page 320) that the engineers of the two different departments, the rolling stock and the permanent way, might persevere in working together for the common good. In the present paper, dealing with an important portion of the rolling stock, the bogie system comes prominently under consideration, as compared with a rigid wheel-base. No one can deny the advantages it confers upon the permanent way: firstly, by allowing of sharper curves, and consequent cheaper construction of road; secondly, by better distribution of the load per axle; and thirdly, by diminishing the lateral pressure on curves, thereby giving greater safety and at the

same time greater economy, owing to the sleepers lasting longer. In his own paper the writer quoted an opinion (page 318) that with a load of 15 tons per axle the lateral pressure on the outer rail of a curve may reach half this amount; and also a calculation that, with the flange rail used on the Northern Railway of France, the Goliath flange rail on the Belgian State Railways, and the bull-head rail on the London and North Western Railway, the pressure of the outer rail on the sleeper is respectively 6·3 and 1·0 and 0·3 ton per square inch, the rolling stock in all three cases having a rigid wheel-base. With the bogie system he is satisfied there would be a great reduction in these pressures for the same weight of rolling stock. In consequence of the general weakness of the road where flange rails are used, base-plates interposed between the rails and the sleepers have been strongly advocated: all the more because in Europe the height of the flange rail is generally greater than the width of its base, thereby increasing its liability to cant and so cause widening of gauge, with consequent risk of derailment. The reason why the American heavier rolling stock can pass over their lighter roads is no doubt that the bogie is there generally in use; and it is matter of regret that its adoption in Europe should have gone on so slowly. Whether it would be most convenient to adopt base-plates for the road or bogies for the rolling stock is a question for the permanent way and rolling stock departments to settle between them: one or other of the two is in many instances urgently required. In England the road is made so strong, as shown by the foregoing figures, that there is no paramount necessity for bogies, while it cannot be denied that under any circumstances they would save the road; and their application to high-speed passenger traffic is already attended not only with great saving to the road, but also with much more comfort in travelling. The introduction of the bogie system in Sweden some years ago on the West Coast Railway, south of Gottenborg, where the road is comparatively light, has not only led to its adoption on the Swedish State Railways, but also lately the engineers of the Finland State Railways having formerly a rigid wheel-base have decided to build nothing but bogie carriages for their lines, after having inspected those on the Swedish railways. The

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large long bogie-wagons are particularly advantageous for long journeys and heavy traffic, such as timber &c.; and for new lines, where no change of system would be involved, their advantages are eminent; but it remains for every railway, on which a different system suited for its special circumstances is already in existence, to consider how far the great expense and trouble of changing would leave any advantage.

As to the special construction of the tube-frame wagons, even admitting that it is the most advantageous for American conditions, it does not follow that it would be so for Europe; it is at least an open question whether the tube frame is really superior to the ordinary frames. The greater number of parts seems rather against it, because ultimately the wear and tear must tell, and justify the old advice not to make in two or three parts what can be made in one. The dead weight would be lessened by using steel, instead of wrought-iron and cast-iron; and although the latter materials may render the construction cheaper in America, where steel is so much dearer, yet considering that in England the extra cost of steel is already so small, and is becoming less almost daily, it seems going a step backwards to use only wrought-iron and cast-iron in the construction of railway wagons. Steel has gradually taken their place with advantage in many parts of locomotives; and whatever crystallization may be going on in steel is going on faster in wrought-iron. Cast-iron wheels may suit American circumstances, but some fifteen years ago the writer strongly objected to their introduction upon European railways; they were introduced by American engineers constructing railways in Russia for La Grande Société, and the latter had afterwards to pay dearly to get rid of them. The present paper he hopes may lead to a more rapid introduction of the bogie system on the continent of Europe, where the railways need it more than in England, as the time and expense required for re-constructing or strengthening the road are so much greater than for adopting bogies. Having recently had an opportunity of inspecting some of the continental railways, he thinks the best long run, as regards both road and rolling stock, is between Paris and Marseilles, on the Paris Lyons and Mediterranean Railway;

the bogie carriage 75 feet long, shown at the Paris Exhibition, runs much smoother than the carriages with fixed wheel-base, and requires less tractive power. Were it not that for the sake of economy the existing old rolling stock has to be used up, the adoption of the bogie system for the continental railways would be the greatest improvement ever introduced; and it is only just to say that the development of this system to its present state of perfection is due to America.

Mr. William Dean supplemented his remarks (pages 513–516) by the following information:—

In regard to the statement in page 482 of the paper, assigning about 90,000 miles as the total for the steel-tire wrought-iron wheel, it has been found on the Great Western Railway that steel tires 2 inches thick on the tread will last from fifteen to twenty years, giving a mileage of from 240,000 to 300,000 miles. The forged wrought-iron wheel centres, after the tires are worn out, are still in perfectly good condition, and simply require re-tiring. Also in a discussion at the New England Railroad Club in Boston on 9th October 1890 (The Railway Engineer, January 1891, page 16), the duration of a pair of steel-tired wheels under a passenger car on the Fitchburg Railroad was given at 399,000 miles by Mr. J. W. Marden, who believed that the cost of running was very slightly in favour of the steel-tired wheel as against the chilled cast-iron wheel.

ON MILLING CUTTERS.

By Mr. GEORGE ADDY, of Sheffield.

Although Milling or shaping metals by revolving cutters has been in vogue for a long period, it is only in comparatively recent times that it has come into general use, namely since the emery wheel was introduced for grinding the cutting edges of the teeth, thus rendering unnecessary the long and tedious process of filing up each tooth separately. Many engineers are of opinion that milling is destined to supersede to a great extent the ordinary planing, shaping, and slotting machines; and it certainly should possess a considerable advantage on account of its continuous action, as compared with those machines having a reciprocating motion, which must inevitably occasion great loss of time. During the last few years the milling process has been improved and brought to great perfection both in America and on the Continent, where it is now successfully used to a far greater extent than in England. Its advantages are so apparent, especially where large numbers of articles of one standard pattern are required, that it seems strange engineers in this country have been so backward in adopting the process. On the other hand those abroad have certainly come to the conclusion that milling not only produces a better finish than planing, shaping, or slotting machines, but in many cases does so in one-third of the time occupied by these machines. Moreover milling has its special uses, and can produce work of such shapes as could not be produced by any other machine. Taking this into account, the writer is of opinion that the reason why milling has been so tardily adopted lies in the difficulties which have presented themselves with reference not only to the cutters but also to the milling machines

themselves. In the present paper therefore he will deal first with milling cutters, and next with some points in connection with milling machines.

Milling Cutters. — It is true that milling cutters are still regarded as expensive both in first cost and in subsequent maintenance; and before the introduction of the emery grinder this was undoubtedly the case, because the re-sharpening of the teeth was so expensive on the old plan. Not only so, but each re-softening of the cutter for the purpose of sharpening deteriorated the steel, and increased the risk of cracking and warping in the re-hardening for use; whereas now all this is avoided by the emery grinder, by means of which the cutters are kept in beautifully sharp condition with little trouble or expense.

Solid Cutter.—Of the different kinds of milling cutters at present in use perhaps the best known form is the key-way or grooving cutter, shown in Fig. 1, Plate 147. This is useful for a variety of purposes, such as cutting key-ways in shafts and axles, and as a parting tool for cutting out test pieces &c. The cutters are made of all sizes, from $\frac{5}{8}$ inch diameter and $\frac{1}{8}$ inch wide up to 11 and 16 inches diameter. The principal points to be attended to are, to employ steel of reliable quality, and to exercise the greatest care in hardening. The cutter exhibited is 14 inches diameter and 1 inch wide, and is made of best-quality crucible cast-steel, of which the analysis is given subsequently (page 537). It is cut on the sides as well as on the circumference, and is used in a machine shop for finishing the ends of drawing-frame beams of the section shown in Fig. 4, a sample of which is also exhibited. This cutter was supplied on 3rd January 1890, and it will be seen that it is scarcely the worse for wear. The work it turns out is also of a satisfactory character as regards finish. The cutting speed is 60 feet per minute.

Although milling cutters made of good material properly hardened and tempered last a considerable time, the teeth ultimately become blunted, and require re-sharpening. It is then that one of the weak points found in cutters of this kind shows itself: namely

the cutter not only loses its diameter but also becomes narrower in grinding; and although still serviceable for grooves of less width than it was originally designed for, it is useless for grooves of standard size, owing to there being no means of expanding it in width.

Several attempts have been made to overcome this difficulty; and in Fig. 2, Plate 147, is illustrated a crude and barbarous method of increasing the width of groove cut, which is by no means to be recommended. After wear of the cutter had taken place, the centre hole, which was originally $1\frac{1}{2}$ inch diameter, was lapped out with lead and emery powder, until sufficiently enlarged to allow of a small wedge D being inserted between the outside of the spindle and the hole in the cutter. This had the effect of making it wobble or sway from side to side in rotating, and become what is commonly known as a "drunken" cutter. The bottom of the groove so cut is not square; but the additional width of groove has been obtained, and that is something. It may seem strange that such a rough and ready plan should have continued in use, to the writer's knowledge, until quite recently.

Jointed Cutter. — Another method occasionally employed is illustrated in Fig. 3, Plate 147. Here the cutter is made in two portions, with a joint at right angles to the axis of the spindle; and these two portions can be packed apart when wear takes place. Whilst this method has some advantage over the "drunken" cutter, it is still liable to the objection that the joint being opened by the packing leaves a strip or fin of material on the work; and this strip has afterwards to be removed either with a file or with some other tool, which it is very undesirable to employ.

Both the foregoing forms of cutter possessed disadvantages tending to make milling too expensive for most machine shops, unless there were very large numbers of articles of slightly different sizes to be milled, so that when the cutters had worn down too small for one size they might still be serviceable for the next size smaller. The ordinary practice was to make the cutter out of one solid piece of high-class crucible cast-steel, and as soon as it became worn to use it

for some smaller size of work; if no smaller size were required, the cutter became useless. On this account milling cutters were looked upon as good tools for certain classes of work, but as luxuries instead of necessaries, and as quite beyond the reach of ordinary engineering shops.

Backed-off Cutter.—In the special form of cutter for milling the teeth of wheels, the expedient commonly known as "backing off" presents one method of ensuring that the width of groove cut shall remain constant notwithstanding frequent re-sharpening; but this principle is applicable only in case the groove is of tapering section, as seen from Fig. 7, Plate 147, and it cannot be employed for a rectangular section. The reason for this is rendered apparent by taking any point A on the face of a tooth, the width of the section of the cutter at this point being shown at B C, Fig. 8. In revolving, the point A is followed by portions of the tooth falling along the arc A D struck from the centre of the spindle E; but the tooth itself is formed from a centre F, in such a way that the width of section along any arc struck from this centre is constant. Therefore along the arc D G described from the centre F the thickness of the cutter is everywhere the same. At the point G however this thickness is shown to be H I, Fig. 8, which is less than B C, thus affording a certain amount of clearance at the sides of the cutter. Treating in the same way a cutter made on this principle, but of rectangular section, Fig. 6, it is apparent that the widths J K and L M at the ends of the arc A D are identical. It is evident therefore that such a cutter without side clearance could not be used in practice. Hence some other solution of the difficulty must be found.

Expansible Milling Cutter.—In Figs. 5 and 9 to 14, Plates 147 and 148, is shown an expansible milling cutter recently introduced by the writer. Instead of being made of one solid piece of steel, it consists of a bush H, usually of some tough material, which fits on the milling-machine spindle S in the usual manner; this bush has a shoulder at one end, the other end being screwed with a fine thread and fitted with a nut and washer. On the body of the bush, between

the shoulder and the washer, are fitted two annular serrated milling discs, made of high-class tool-steel; the joint JJ between them is not at right angles to the axis of the spindle, but is slightly diagonal or oblique. A key let into the bush at K prevents the discs from revolving on the bush; the nut and washer secure them endways, thus completing the cutter. A cutter of the size shown in Fig. 5, 9 inches diameter and $1\frac{1}{2}$ inch wide, was supplied in April 1889 to Messrs. Sir W. G. Armstrong, Mitchell and Co., Elswick; and it will be seen that, although when the discs are nipped together the cutter is only $1\frac{1}{2}$ inch wide, each half would of itself, owing to the oblique or diagonal joint, cut a groove 1 inch wide, as each disc is 1 inch broad at the widest side and $\frac{1}{2}$ inch at the opposite side. Thus not only is provision made for ordinary wear and tear, but this cutter may also, if desired, be packed out to cut several sizes from $1\frac{1}{2}$ up to 2 inches, without leaving on the work a strip or fin of uncut material to be removed afterwards by some other tool. Samples of the work done by this cutter are exhibited.

One of these expansible milling cutters was supplied in March 1890 to the Royal Arsenal, Woolwich. It is of rather an unusual size, being 10 inches diameter and 3·3 inches wide, with $\frac{3}{8}$ inch expansion. It is used for milling the hoods of 4-inch breech-loading guns.

Many engineers might be inclined to adopt milling, but are deterred by the expenditure involved in the necessity of getting a separate cutter for each size of groove required. They may have five or six different sizes, differing only perhaps 1-16th of an inch from one another; and not caring to get a separate milling cutter for each size, they contrive to obtain the sizes by planing or shaping; whereas they would not object to get two milling cutters, if these would cut six sizes between them. In such cases this expansible cutter will recommend itself, as well as where large numbers of grooves have to be cut of one exact width, and where accuracy is of the utmost importance.

Another advantage gained with the expansible cutter is the saving of steel. The central bush is not only useful in supplying a quick and easy method of regulating the width of the cutter, but it

also causes the hole in the cutter discs to be much larger in diameter than the hole in solid cutters. The piece cut out of the centre of a large disc will therefore itself make a cutter of smaller size. Thus in a cutter of 10 inches diameter it is easy to turn a disc of 5 inches diameter out of the centre, which will come in for another cutter; so that by this plan two cutters are obtained from the same piece of steel which on the old plan would have made one cutter only.

Diameter of Cutter.—To look upon milling as suitable only for cutters of small diameter has long appeared to the writer a mistake; and he considers that in many cases cutters of comparatively large diameter may be used with great advantage. Acting on this opinion, a milling cutter has recently been made 22 inches diameter and $5\frac{1}{2}$ inches wide, which is shown in Figs. 19 and 20, Plate 150. The teeth are here formed upon steel rings of the required sections, and clamped between the flanges of a cast-iron boss, which is secured upon the spindle in the usual way; thus only the cutting parts are formed of expensive material, instead of the whole cutter as heretofore. One advantage of using cutters of large diameter is that, as there are more cutting edges to do the work, the teeth keep sharp longer, and the cutting speed can be increased accordingly. Large cutters, having hardened steel teeth inserted in an iron block and secured by set-screws, as shown in Figs. 21 to 24, have been used occasionally; but so many separate parts are objectionable, on account of the liability of the teeth and set-screws to become loose and cause breakages. In Figs. 25 to 30, Plate 151, are shown other forms of milling cutters in use at various works.

Cutting Angle of Teeth.—After careful examination of a large number of milling cutters, the writer has found that considerable diversity exists with respect to the cutting angle and the pitch of the teeth. It is evident that, in order to produce the best result, the adoption of the most suitable cutting angle should receive the same close attention that is now universally bestowed upon the ordinary tools for turning and planing. It is of course desirable to adopt a mean cutting angle, in order that the same cutter may work equally

well upon either cast-iron, wrought-iron, or steel. As the result of considerable research and of the experience gained by the writer during the last few years, he decided to adopt the standard form of tooth shown in Fig. 16, Plate 149, in which the front of the tooth AB, instead of being truly radial, has a backward inclination of 10° from its cutting edge. At the same time the cutting angle A B C is made 70°, the clearance angle being thus 10°. A comparison of this tooth with the most approved form of tool point for planing &c. is shown in Figs. 17 and 18. To produce the best possible finish on flat surfaces, the teeth of all cutters, unless very narrow, should be cut spirally across the face of the rim, as shown in Fig. 15.

Pitch of Teeth.—For obtaining a suitable pitch of teeth for milling cutters of various diameters, there exists no standard rule, so far as the writer can ascertain, the pitch being usually decided in an arbitrary manner, according to individual taste. For estimating the pitch of teeth in a cutter of any diameter from 4 inches to 15 inches, the writer has worked out the following rule, which he has found very convenient and capable of giving good results in practice :—

$$\text{Pitch in inches} = \sqrt{(\text{diameter in inches} \times 8)} \times 0{\cdot}0625.$$

Speed of Cutters.—The cutting speed for milling was originally fixed very low; but experience has shown that with the improvements now in use it may with advantage be considerably increased, especially with cutters of large diameter. The following are recommended as safe speeds for cutters of 6 inches diameter and upwards, provided there is not any great depth of material to cut away:—

Steel	36	feet per minute,	with a feed of	$\frac{1}{2}$	inch per minute.		
Wrought-Iron	48	„	„	„	1	„	„
Cast-Iron	60	„	„	„	$1\frac{2}{3}$	„	„
Brass	120	„	„	„	$2\frac{2}{3}$	„	„

Should it be desired to remove any large quantity of material, the same cutting speeds are still recommended, but with a finer feed. Speaking generally, the cutting speed does not receive the attention it requires; in many cases the speed is actually unknown to the attendant, and consequently the machine is run at a lower speed than might safely be employed. The following simple rule, which can

be used by any ordinary workman, removes this uncertainty:—Number of revolutions per minute which the cutter spindle should make when working on cast-iron = 240 divided by the diameter of the cutter in inches.

Milling Machines.—The milling machines originally imported from America and the Continent were deficient in the solidity and stiffness which constitute the first requirements for the production of good work; it is absolutely essential that there should be an entire absence of vibration. Moreover some of the so-called universal machines were sorely cramped to get all their motions in; and in this respect it might truly be said that it was better to do one thing only and do that well. Great improvements have since been effected both in the machines and in the arrangement of their spindles; and no trouble should now be experienced for want of rigidity. Many machines yet in use however are faulty; and the writer believes there are many cases where milling cutters are not giving the best results through lack of strength and rigidity in the machines. A few months ago his attention was drawn to some cutters which were not doing satisfactory work, and an enquiry was made as to whether this was not caused by the pitch of teeth being too coarse for the work; he suspected however that the fault lay with the machine, and examination showed that there was about 3-32nds of an inch of spring in the spindle. There is little doubt that in some cases teeth are broken, and cutters condemned as made of poor material or improperly hardened, when the fault is really with the machine; it cannot be too strongly impressed on makers of milling machines that rigidity must be the first consideration. Solidity of construction has hitherto been characteristic of British work when compared with continental, both in engines and tools; and it is to be hoped that this will continue to be the case.

An example of solidity of construction and ingenious combination of cutters is afforded by a milling machine at some works in Lancashire, which has been specially designed for milling simultaneously seven faces of a mule headstock, shown in Figs. 34 to 37, Plate 153. Before this machine was made, the cost of getting

up these faces by planing, which required several settings, was 5*s.* each headstock; they are now done by this machine at a cost of 10*d.* each. The machine is shown in Figs. 31 to 33, Plates 152 and 153, and in general appearance is like a planing machine. To the foundation bed B on each side are securely bolted the massive uprights U, and on the top of these is bolted a cast-iron cross-slide C. The table T on which the work is carried travels on faces cast on the foundation bed. The feed motion for the table is obtained by means of a stationary screw fixed to the underside of the table, and a revolving nut, on the circumference of which are teeth gearing with a spur wheel that is driven by bevil wheel and pinion from the feed shaft F; the latter is driven by a cone pulley containing a differential motion and friction cones, by means of which a quick return motion is given to the table. The seven milling cutters, 1 to 7, are fixed upon mandrils, which are carried by heads working in slides on the uprights and on the cross-slide; six cutters are on the front of the machine, three of them on vertical spindles on the cross-slide, and three on horizontal spindles on the uprights; the seventh cutter is on a horizontal spindle on the back of the left-hand upright. Each cutter head is independent, and can be adjusted vertically and horizontally in slides upon the faces of the uprights, by means of bolts and T slots. Each cutter mandril is driven by spur wheel and pinion, and belt pulley driven from the countershaft S on the back of the uprights. Cutter 1 operates on face 1 of the mule headstock, 2 on 2, and so on. The belt pulleys driving the three cutters that are carried on the cross-slide are in a horizontal position, and are driven by half crossed belts. The table is provided with two stops fixed in a T slot, for disengaging the friction clutch from the cone by which the feed motion F is driven. The countershaft S on the back of the machine is driven by fast and loose pulleys, and is provided with a universal strap-shifting arrangement.

Steel for Milling Cutters.—As the quality of steel for milling cutters is of vital importance in regard both to their cost and to their durability, the firm with which the writer is connected, Messrs.

Dickson Brothers and Co., have been devoting themselves to the production of steel blanks or forgings which should be easy to machine and should harden quite soundly. The accomplishment of this object has been the aim of many Sheffield works, and almost every manufacturer of crucible cast-steel has some special mixture which he considers most suitable for such a purpose. This steel is made largely from the best brands of Swedish iron; and specimens of that which has been found suitable for milling cutters are exhibited in every stage from the ingot to the finished cutter.

Self-hardening Steel.—Lately self-hardening steels have come into general use for turning and planing tools. Sample milling cutters made from self-hardening steel of the brand "Ivanhoe" are exhibited.

Analysis of Steel.—The following are analyses of milling-cutter blanks made from best-quality crucible cast-steel and from self-hardening "Ivanhoe" steel:—

	Crucible Cast-Steel. Per cent.	Ivanhoe Steel. Per cent.
Carbon	1·2	1·67
Silicon	0·112	0·252
Phosphorus	0·018	0·051
Manganese	0·36	2·557
Sulphur	0·02	0·01
Tungsten		4·65
Iron, by difference	98·29	90·81
	100·000	100·000

Discussion.

Mr. Addy said that for the previous meeting in Sheffield, for which this paper had been prepared, the cutter 9 inches in diameter and $1\frac{1}{2}$ inch wide, mentioned in page 532, had been kindly lent by Messrs. Armstrong Mitchell and Co., Elswick; but they had written to say they were sorry that they were unable to lend it again for the present meeting, as it was just now in use on work which could not be stopped without serious inconvenience. At the Sheffield meeting he had also exhibited some specimens of work done by a cutter $1\frac{1}{2}$ inch wide, expanded to 2 inches; that was an unusual amount of expansion, and more than he recommended for general use. The solid cutter mentioned in page 529 and shown in Sheffield, 14 inches diameter and 1 inch wide, he was not able to exhibit again on the present occasion, as it could not be spared now from the works where it was in use.

A cutter exhibited of 12 inches diameter and $2\frac{3}{4}$ inches width, which he had supplied a short time since to the Nine Elms locomotive works of the London and South Western Railway, had been kindly lent by Mr. Adams. It was used for milling out the heavy spring buckles for the locomotives, of which Mr. Adams had sent a specimen before milling and another after cutting. He had also sent a portion of a coupling-rod of **I** section, together with the two cutters by which the channel in each side and the rest of the surfaces had been milled.

A sample of the work done by some of these cutters supplied about fifteen months ago to the Taff Vale Railway had been kindly sent by Mr. Riches, from whom a letter had been received respecting it (page 552). He should have been glad if the amount of expansion of the cutters used had been stated, and if the cutters themselves had been exhibited. Of all the expansible cutters in use, no complaint had in any instance been received of their failing to do as much work as the ordinary solid cutters.

The mule headstock mentioned in page 535, and shown in Figs. 34 to 37, Plate 153, was again on view, having been kindly lent by Messrs. Hetherington and Sons, Manchester. The samples

of cotton machinery exhibited had been kindly lent by Messrs. Lord Brothers, Todmorden, who had gone in extensively for milling.

There were also shown several other specimens not referred to in the paper. Wasters were by no means rare in making cutters; and he called attention to a milling-cutter blank which looked all right on the outside, but in boring it out an internal flaw had been detected, which would have caused the cutter to crack in hardening. In another cutter exhibited, which did crack in hardening, a flaw had not been detected beforehand; but fortunately it had been detected in time in the hardening, before all the final labour of grinding the teeth had been put upon it.

Some milling-cutter blanks made from self-hardening steel (page 537) were also exhibited. Until recently it had been thought that self-hardening steel could not be used for milling cutters, on account of the difficulty in making them of it; but it had been found that this steel could be annealed after it had been made into the blank, so that the blank could be turned up in the lathe. Of course it was not so easy to turn up as the ordinary steel, but still it was workable. There were two or three backed-off cutters among the specimens exhibited, one of which was made of self-hardening steel; and he had brought it to show that this steel was really practicable, even for milling cutters which required so much work put upon them as the backed-off cutter.

Although milling had been known for 226 years, having been invented he believed by Dr. Hook in 1664, it was safe to affirm that not more than 60 per cent. of the engineering establishments in Great Britain yet possessed a milling machine.

Mr. E. R. Dolby, referring to the built-up milling cutter shown in Fig. 21, Plate 150, in which it was seen that the separate teeth were inserted radially, mentioned that some large saws or milling discs with inserted cutters had been used for years by Messrs. Taylor Brothers at the Clarence Iron Works, Leeds, for cutting out the webs of crank-axles. As shown in Figs. 38 and 39, Plate 154, the method adopted was to drill a hole through the crank forging at the inner extremity of each side of the web to be cut

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out, and to run a saw-cut or milling-cut along each side of the web, up to the drilled hole at the extremity, and then to break off the web between by driving wedges at its outer extremity, so as to break it across from hole to hole. In the machine employed for the purpose, which was made by Messrs. Kitson and Co., Leeds, two large milling discs for running the cut along each side of the web were fixed at the proper distance apart on a heavy spindle carrying a worm-wheel 4 feet diameter, which was driven by a worm about 9 inches diameter. Each disc was 3 ft. 11½ ins. diameter, Fig. 40, and was made out of a steel plate 5-8ths of an inch thick, turned down to 9-16ths inch thick. Into the circumference were fitted forty-eight cutters of three different shapes, ABC, Figs. 41 to 49, in sixteen successive sets of three each. In each set the first cutter A had its cutting edge pointed, Fig. 44, Plate 155 ; the next following B, Fig. 46, had its edge made fuller and rounded; and in the third C, Fig. 48, the cutting edge was square right across the face, so as to finish the cut to the full width of 11-16ths inch, Fig. 49. The machine was run at a speed of about 15 feet per minute, measured at the tips of the cutters. Instead of being inserted radially as shown in Fig. 21, the cutters were fixed with their faces inclined to the radius, Fig. 42, so as to cut with a sharper angle. Each cutter was 2¾ inches long and 11-16ths inch thick, and was secured in a rectangular notch by means of a wedge D driven in front of it; the back of the cutter was V shaped, as was also the back of the notch into which it fitted, whereby all side shake was prevented. The angle at which the cutters were inclined to the radius was first of all made 20 degrees; and this angle was found to answer well for sawing steel. But when wrought-iron was attempted to be sawn at the same angle, the cutters dug into it and stuck; and for sawing wrought-iron they had to be put at an angle of 16° instead of 20°. The cutters stood out ¾ inch from the rim of the steel plate in which they were fixed, the diameter of the complete disc being 4 feet 1 inch over all. It was possible to regulate the distance between the two discs by putting washers in and tightening up. In a crank forging twelve inches thick, of either steel or iron, the machine would cut with both discs at once through a distance of eleven inches along each side of the web in two hours.

Mr. W. J. Tomes, from the London and South Western Railway locomotive works, noticed that in page 529 of the paper milling cutters were said to be still regarded as expensive in first cost. As compared with slotting and planing tools, no doubt milling cutters were more expensive in first cost; but after their adoption it was found that for such work as that now exhibited from Mr. Adams, and for other portions of locomotive work, the saving resulting from the use of milling cutters was at least 30 or 40 per cent. At the Nine Elms locomotive works, connecting-rods and coupling-rods were forged and the ends stamped out; and after the two ends had been drilled, the rod was then finished completely in a milling machine with a single cut off each surface. The piece of coupling-rod exhibited of **I** section had only had one cut taken off all over: that is, one cut off the top, one off the bottom, one off each side, and one out of each channel; it had of course to pass six times through the milling machine, but each time a separate portion of the surface was cut, no part being milled more than once. Where such work had to be done in duplicate, it naturally came still cheaper. But in small shops, where there was varied work, he doubted whether milling tools were cheaper than ordinary planing or slotting tools. The spring buckles, of which specimens were shown, varied in width by quarters of an inch. If the expanding cutters were not used, not only would a fresh cutter be required for every size, but also the gap in the buckle would decrease in width as the sides of the cutter wore; for this work therefore the expanding cutters were very useful.

With reference to the use of self-hardening steel for milling cutters, it had been found to take much longer to work up; and sometimes it was too soft, and then there was the trouble of re-hardening it. It had been tried also for twist drills; but these were much more expensive to make of self-hardening steel than of ordinary steel.

As to the stiffness of the milling machines, he agreed with the author's remarks (page 535). If milling machines were made much stiffer than they generally were, it would be practicable to use a much larger cutting diameter, and so to cut at a much higher speed. The

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milling machines at present in use at Nine Elms were found to be not stiff enough; and in some instances the circumferential speed of the cutter had had to be reduced on that account below the cutting speed mentioned in the paper (page 534).

With regard to the pitch of the teeth in the milling cutters, where there was a great diversity of work it had been found best to have one pitch for brass, another for wrought-iron, another for cast-iron, and another for steel; but where there was not much brass or cast-iron work it was better to have only one pitch. Having worked out the rule given by the author (page 534), he found it agreed fairly with the pitch of teeth he was using. In milling brass work or cast-iron work where the scale was on, it had been found that the teeth were worn away very much; but with the aid of the sand-blast for taking the skin off first, the work could be done economically by the milling cutters.

Mr. John H. Briggs rather demurred to the statement made in page 534 of the paper, that the cutting speed for milling had originally been fixed very low, but experience had shown that with the improvements now in use it might with advantage be considerably increased, especially with cutters of large diameter. In Mr. Ford Smith's paper, read before this Institution in April 1883, upon the cutting of metals, it had been stated (page 248) that a milling cutter, with a plentiful supply of oil or soap and water, could be run at from 80 to 100 ft. per minute when cutting wrought-iron. He had never been able himself to get near such a speed: and he believed that Mr. Smith had since somewhat modified his opinion as to the speed at which milling cutters ought to be run. As the result of ordinary workshop routine he had found that for cutting wrought-iron with a milling cutter taking a cut of one inch depth—which was a different thing from mere surface cutting—a circumferential speed of from 36 to 40 ft. per minute was the highest that could be attained with due consideration to economy and to the time occupied in grinding and changing cutters; the feed would be at the rate of 5-8ths inch per minute. Upon soft mild steel about 30 ft. per minute was the highest speed, with $\frac{1}{4}$ inch depth of cut and $\frac{3}{4}$ inch feed per

minute. Upon tough gun-metal 80 ft. per minute, with $\frac{1}{2}$ inch depth of cut and $\frac{3}{4}$ inch feed. For cutting cast-iron geared wheels from blanks previously turned, and using in this case comparatively small milling cutters of only $3\frac{1}{2}$ inches diameter, the speed was $26\frac{1}{2}$ ft. per minute, with $\frac{1}{2}$ inch depth of cut and $\frac{3}{4}$ inch feed per minute. In cutting the edges of slide-valves made out of hard close-grained cast-iron, which was a rather crucial test for milling cutters because the valves were apt to be chilled at the edges, cutters of $9\frac{1}{4}$ inches diameter did the best work and gave the best return at a speed of 30 ft. per minute, with $2\frac{1}{4}$ inches depth of cut and a feed of 5-16ths inch per minute, Fig. 52, Plate 155. It was better to cut them fixed vertically at this moderate speed with two cutters than to cut the edges alone at a faster speed. In milling with a train of cutters, say in the case of gun-metal joints, Figs. 50 and 51, Plate 155, where there were five faces to be cut by three cutters at one pass—outside and inside one jaw, inside the bottom of the gap, and inside and outside the opposite jaw—the speed was 53 ft. per minute, with 5-8ths inch feed per minute, and the depth of the cut was $1\frac{3}{8}$ inch. That work was well finished, without deforming the gun-metal; but he had found gun-metal difficult to hold in position against such heavy cutting; it was apt to spring out, especially in the milling of joints. In milling steel bars over a face of 4 inches width with a cutter having spiral teeth, the cutting speed was about 21 ft. per minute, with a feed of $\frac{3}{4}$ inch per minute; the depth of the cut at each pass was not more than 1-32nd inch on account of the great width.

In America it was generally considered an advantage to keep the diameter of the cutter as small as possible. This held good for face work, where there was a great breadth of cutting; but where edge cutting was required he thought it was much better to have a cutter of as large a diameter as could be got in, compatibly with carrying the end of the milling spindle in the outer bearing of the machine. There was no doubt that the great fault of most of the present milling machines was that they were too light, and that the outer bearing was too small to carry any great strain of cutting without a perceptible deflection and vibration, which very much interfered

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with the quality of the work produced and also with the life of the cutter.

With regard to the pitch of the teeth, if it was made very fine there was a difficulty in grinding them properly, because the diameter of the emery wheel had to be kept so small, in order to avoid any risk of touching the next tooth in getting clear from the one it was grinding.

Mechanical engineers in this country had been reproached for not having adapted milling machines more extensively to their workshop requirements. At all events they had utilised these machines already to a great extent; and he had no doubt that as the system of reproduction from standard parts was elaborated, milling machines would come more and more into use. Undoubtedly for irregular forms, where great numbers of one sort had to be produced, nothing would come near the milling cutter. But among the specimens now exhibited he noticed a plain wrought-iron bar, which looked like the guide for a water-tight door between the compartments of a ship. Such work he thought could be done upon a planing machine as well and as quickly and as cheaply as with a milling machine. The length of the bar he presumed would be about 7 feet; and he thought that a planing tool with a good stiff cut would get rid of the metal better than a milling cutter. A milling machine he considered was not generally so suitable for getting rid of a large mass of metal, but it did very well for light work.

Mr. J. Macfarlane Gray pointed out that the rule given in the paper (page 534) for the pitch of the teeth in a milling cutter might be put into a somewhat simpler form for more convenient use as a plain workshop rule, by saying that the product of the pitch in inches multiplied by the pitch in thirty-seconds of an inch was equal to the diameter in inches. A still more simple way of stating what was substantially the same rule was to say that the number of teeth in a milling cutter ought to be one hundred times the pitch in inches: that is, if there were 27 teeth, the pitch ought to be 0·27 inch.

Mr. M. Holroyd Smith enquired what was the method of cutting and sharpening the teeth of the milling cutters. It was mentioned in page 529 that they were sharpened by the emery grinder; and he should be glad to know how this was done, and also how the teeth were cut originally.

Mr. James Holden said that at the Stratford Works of the Great Eastern Railway a great deal of work was now being done with milling machines, some of which had been in use since 1878. The whole of the cutters there used were made on the spot. The smaller cutters were made of the very best cast-steel; and many of the large cutters, the largest being 14 inches diameter by 6 inches wide, were made of steel which had cost as much as £8 8s. per cwt. The teeth were all cut spirally; in the larger cutters they were planed out as nearly perfect as they could be, and were dressed up afterwards by grinding with emery wheels. A good deal of difficulty had been experienced in getting the large cutters to stand, when made all in one piece of high-class steel; but latterly they had been built up of five or six discs, each about an inch thick; and instead of being made of high-class steel, the discs were simply hammered down out of old Bessemer axles. They were easy to work, and cheap. After the teeth had been cut upon them while all held together, they were taken apart, and each disc by itself was brought to a low red heat, and the cut edges were dipped in prussiate of potash and then cooled in water. Afterwards the whole were put together again, and the complete cutter was dressed with an emery wheel, without any difficulty being experienced. Besides being so cheap, these built-up cutters lasted well; and they never had any of their teeth crack away in the hardening, as they did when made of high-class steel. The milling work, which was being considerably extended, came out very well; it was more cheaply and quickly done, and required no finishing. The cutter itself formed the gauge for the work, so that the latter required only careful setting, and practically no marking off.

Mr. George Richards exhibited specimens of milling cutters constructed with separate teeth inserted, which he had had in use for the past year. They had not been used long enough to enable him to speak of them for general purposes; but for cast-iron work they had been found to answer admirably. For wrought-iron work there had as yet been no experience with them; but cutters of this make were now in course of construction for testing thoroughly that kind of work. The sole object in designing this make of cutters was to meet the difficulty and expense of introducing milling. As a maker of milling machines he was constantly finding that engineers entered into milling readily enough at the outset, because they saw it was being done in other shops; but after a time difficulty and trouble arose: the foremen did not take an interest in the work, and in many cases the milling machines died a natural death. At his own works he had ten milling machines working with great advantage; and when other engineers had come to see what they were doing, he had always warned them that unless they were prepared to go into the matter thoroughly, and to get proper tools and skilled men to work them, they had better leave milling alone. Judging from his own experience, a great deal of time had been wasted in trying to adapt milling to various kinds of work, in comparison with the good that it had accomplished; and the many failures had caused milling to be blamed and discredited. As compared with planing however, he had found that in milling pieces of medium size the expense of the milling cutters themselves was the main cost. In other words, if everything else was taken into consideration, milling was considerably cheaper in every way than planing, excepting only for the cost of the cutters. It was this conclusion which had led him to manufacture milling cutters with inserted blades, as shown in Figs. 53 to 60, Plate 156.

The two cutters now exhibited with inserted blades were made of Bessemer steel heads or blanks, fairly hard, but soft enough to be themselves milled easily. One of them had now been in use for eighteen months, and had been constantly working in the milling department. It was the first cutter he had made of the kind, and it had already had four sets of blades put into it. The grooves for the

blades were simply milled out in straight lines along the block with saws; and the steel blades were then pushed into them, and locked tight by driving hardened steel pins into the slightly taper holes drilled longitudinally in the block from each end; in the long cutters a recess cut into the block in the middle of its length, Fig. 53, Plate 156, allowed of driving the pins out again, whenever the blades had to be taken out. The wedging pins, Fig. 60, were driven in between every four of the blades. This method of holding the cutting blades in the block was the result of experience in the construction of adjustable-blade rimers, which he had been making in this way for many years; and he was fully satisfied of the strength and the stiffness with which rimer blades were held by this mode of wedging up. The steel for the milling blades was carefully rolled, and then sand-blasted so as to remove the scale; then cut into the lengths required, Fig. 59, and hardened and tempered; then forced into the grooves in the block and keyed up; and then the whole milling cutter was ground like an ordinary cutter. The steel in these separate blades he imagined was of a higher quality than could be found in the teeth that were formed solid on milling cutters. The reason was that, unless some special appliances were used for heating the solid cutters, it was difficult to get a uniform heat throughout the mass of metal; so that, when they were dipped in water or other hardening mixture, they got soft places in the cutting edges, especially at the ends of the cutters. In order to get the whole cutter hard, the ends were generally overheated; and then the result was that the ends of the teeth soon snapped off when put to work, and for some purposes the cutter was spoiled. The separate inserted blades which he was using were of three different sizes; the largest used up to the present time were $\frac{3}{4}$ inch deep and $\frac{1}{8}$ inch thick, Fig. 59, and projected $\frac{1}{4}$ inch from the block, Fig. 56, so that they would stand a great many grindings. In using solid milling cutters of the general form and of medium size he had found that after a few grindings the teeth had become so wide on the face that it was difficult to get an emery wheel in between; they then required to be softened and re-cut. The cost of the separate inserted blades was low, the steel used costing less than

(Mr. George Richards.)

2*s.* a lb.; and the quantity of steel required was small. The length of time required for changing the blades in a cutter was less than an hour.

Another advantage presented by the milling cutters constructed with separate inserted blades was that the shank which fitted into the spindle of the milling machine could here be made solid with the cutter blank. With a solid shank the cutter was of course rather more bulky; but it was important to be able to make the shank solid with the cutter, because at certain works in Lancashire, at which milling was being largely done, it was insisted upon that every cutter should have its own mandril to fit into the spindle of the milling machine, in order to make sure of its running true. By the plan of having a soft blank, which would last for a good many years, it was possible to have the shank solid with the cutter. How far this construction of milling cutter with inserted blades was novel he did not know; but at any rate his own experience of it had been very favourable.

With the speed of milling cutters he was chiefly conversant in regard to cast-iron; and one of the first things to be taken into consideration was that some method should be used of ascertaining what the cutters were really doing. In his own works there was fixed on every one of the drilling, boring, and milling machines, a little brass plate, on which the speeds of the several steps in the driving cone were traced in the form of a diagram, so that the foreman could see at a glance at what speed the machine was running. Tablets were also hung alongside the machines, especially the milling machines, giving the speeds to be used with the different cutters according to the material worked; and the men were obliged to work to those rules. Generally it was difficult to get the milling cutters and other machines worked as rapidly as they might be worked, because the men objected to work them to their full capacity; but with these tablets and speed diagrams it was no longer at the option of the men to work the machines below their full capacity, because they had simply to conform with the rules, which prescribed the position of the belt on the driving cone and the rate of feed appropriate to the material. This plan saved a good deal of dispute

and argument, which was an important matter. At his own works the speed of the twist drills had been raised, against the opinion of the men that the drills would thereby be spoiled. The same had been the case with the milling cutters. It was true that the speed assigned for milling cutters working on cast-iron in America was rather too high for this country; but that was because American cast-iron was much easier to cut, although it was closer and harder for wear; whereas in English cast-iron there was something that looked like a little black dirt, which spoiled the cutting edges, and necessitated a slower speed. Another important point with regard to the speed of milling in the United States was that it was there the practice for nearly all the milled work to be pickled with sulphuric acid before milling. The same practice was followed at some of the works in this country, but it was not a general process. All the work that had been milled hitherto at his own works had been pickled before milling, by immersing it for ten or twelve hours in a bath of sulphuric acid diluted with twenty times as much water, and thoroughly washing it with water when taken out. With cast-iron so treated it had been found that the capacity of the milling cutters was nearly doubled. Remarkable though this result might seem, he believed it could be borne out by the experience in other works also.

Mr. Addy said that in the various works in which he had been concerned in the introduction of milling cutters there had been no need to employ skilled workmen (page 546) for the milling machines; in nearly all cases, even in some of the largest works, intelligent labourers alone were engaged. The milled work now exhibited from the London and South Western Railway he believed had all been done by a labourer. At Messrs. Hetherington's works in Manchester, where a large amount of milling was done, labour of that kind was used; and in nearly every other case that he had known labourers were employed, instead of skilled workmen. Moreover it was common for one man to take care of two milling machines, and sometimes of three. The man who attended to the mule-headstock milling machine, shown in Plates 152 and 153, also attended to two planing

(Mr. Addy.)

machines. That accounted for a large piece of work like the mule-headstock being now done by milling at a cost of tenpence, which used to cost five shillings by planing up.

In cutting wrought-iron and steel, it was always advisable to have plenty of soap and water (page 542). Instead of having a can and simply dropping water from it, there should be a circulating pump with a pipe not less than $\frac{3}{8}$ inch bore, so as to keep the cutter nicely cool, and also to carry off the cuttings.

With reference to the quality of the steel for the milling cutters, he did not see how a higher quality could be used by making the cutting blades separate, inasmuch as the cutters with solid teeth were themselves made of razor steel, than which it would be impossible to get better steel for the purpose.

As illustrating the importance of settling the speed at which the milling cutters were to work (page 548), he might mention that at one works he had seen a milling machine running with cutters 8 inches diameter, and on a subsequent visit had found the same machine running with 14-inch cutters at just the same speed of revolution and just as satisfactorily: showing that the smaller cutters had not been driven fast enough. In this way it often happened that a milling machine did not do anything like the amount of work that it was possible to do; in many cases the speed could be increased with safety and advantage.

The cutters made by Mr. Holden from old axles (page 545) had undergone a sort of case-hardening with which he had not experimented; and he should like to know whether the life of a cutter when made of mild steel case-hardened was the same as when made of the best crucible cast-steel. If a cutter made of inferior steel case-hardened would last as long as one made of the best crucible cast-steel, it would be well to begin at once to use common steel; but so far as his experience went, the higher the quality of the steel, the longer was the life of the cutter; and this in some measure compensated for the additional first cost.

With reference to one of the samples exhibited, and the remark (page 544) that a planing machine would do the work as well and as quickly, he did not know that this was the case; and

Messrs. Armstrong, from whom the specimen came, were evidently not of that opinion, otherwise they would not have used the milling cutter for this purpose, but a planing machine. Most engineering shops had plenty of planing machines; and these would therefore be used wherever it was possible, if the work could be done as cheaply as by milling.

The large cutters for sawing out the webs of crank axles, described by Mr. Dolby (page 539), no doubt served very satisfactorily the purpose they were intended for; and mention had been made (page 540) of the angle adopted at Messrs. Taylor's works for the inclination of the face of the teeth to the radius, namely 20° for cutting steel and 16° for wrought-iron. The inclination of 10° given in the paper was intended to be used in conjunction with a mean cutting angle of 70°, for enabling the same cutter to work equally well upon either wrought-iron, cast-iron, or steel. If however engineers would keep separate cutters for wrought-iron, cast-iron, and steel, it would be found that a different angle for each material would be more suitable; and probably the rake of 16° for wrought-iron would be found to be correct. But so long as cutters were used indiscriminately on different materials, he thought it advisable to have a rake of 10° with a cutting angle of 70°.

Sand-blasting certainly did remove the sand from the surface of castings, and also take the skin or scale off, and thereby facilitate the cutting (page 542); but he did not think it was in general use at the present time for this purpose.

The teeth of the milling cutters (page 545) were formed on the bored and turned blank by means of a V shaped circular cutter; and after hardening and tempering, a keen cutting edge was put on each tooth by means of a rapidly revolving emery wheel.

The President said milling was certainly growing, and taking the place of ordinary workshop tools; and he was disposed to think that it would grow a great deal more, although he had had but little experience of it himself. He was sure the Members would have much pleasure in joining him in a vote of thanks to Mr. Addy for his paper.

Mr. T. Hurry Riches, Member of Council, being unable to be present, sent a wrought-iron block $5\frac{5}{8}$ inches cube, in which one groove had been milled by an ordinary cutter at the Taff Vale Railway locomotive works, Cardiff, and two other grooves of the same width by the expansible cutter; and he furnished the following particulars of the relative work done:—

Description of Cutter.		Ordinary.	Expansible.
Diameter of cutter	inches	5·000	4·437
Circumference of cutter	inches	15·70	13·94
Revolutions of cutter per minute	revs.	22	22
Speed of circumference per minute	inches	345·4	306·7
Speed of table travel per minute	inch	0·428	0·428
Depth of cut	inch	0·750	0·500
Width of cut	inch	0·875	0·875
Material cut per minute	cub. inch	0·281	0·187
Material cut per inch of cutter circumf.	cub. inch	0·0008	0·0006

One-third more material per inch of circumference was therefore cut by the ordinary cutter than by the expansible. The above work may be taken as the maximum in each instance, because when more was attempted the cutters gave way. The writer's observation of the working of the expansible cutter leads him to think that it should be arranged to place some cutting teeth on the inner face of each of the two discs forming the cutter, so as to remove the present tendency to leave a fin or fringe between the discs when expanded, as it appears to him that the breaking of the teeth of the expansible cutters was largely due to this tendency: the following teeth having no side-cutting edge appeared to jag, and so to injure the teeth.

Another kind of stepped milling cutter was tried under two conditions of speed in the same machine: namely in single gear, making 40 revolutions per minute; and in double gear, making only 18 revolutions. The cutter was 4 inches diameter and 12 inches wide, and the width of cut was $10\frac{1}{4}$ inches in each case. At the higher and lower speeds respectively the depth of cut was 5-16ths

and 3-8ths of an inch; the travel of the table 1·3 and 0·625 inch per minute; and the quantity of material cut 4·16 and 2·40 cubic inches per minute. In both instances the cutter was worked up to its maximum speed before it commenced to give way, in order to ascertain definitely the relative advantage of working at a high speed with a light cut as against a low speed with a heavy cut.

MEMOIRS.

Samuel Anderson was born at Blackhill in the county of Durham on 7th November 1847. In 1858 his father left the Consett Iron Co. to undertake the management of the Westbury Iron Co. in Wiltshire, where he completed his son's education at private schools. In 1863, at the age of sixteen, he was apprenticed to Mr. Joseph Taylor, mechanical engineer, Birmingham, for the term of three years. In 1866 he was appointed foreman of the engineering department of the Westbury Iron Works, and a few years later sub-manager. On his father's death in 1876, he became general manager and secretary, which position he held to the time of his death on 19th March 1890, at the age of forty-two. By taking advantage of the latest inventions for saving of fuel and labour, wherever these could be practically applied at Westbury, he enabled the works to compete successfully with those in the larger and more favourably situated iron-manufacturing districts. He became a Member of this Institution in 1884, and was also a member of the Iron and Steel Institute and of the South Wales Institute of Engineers; and he was a regular attendant at the meetings.

Nathaniel Clayton was born in Lincoln on 25th August 1811, his father being a packet-boat proprietor. He served his apprenticeship at the Butterley Iron Works. Before he was twenty-one years of age, he ventured upon hiring a vessel of some size to convey a cargo of goods from Lincoln to London. Losing his father early in life, he became manager and subsequently proprietor of two packet-boats plying between Lincoln and Boston; these were originally drawn by horses, until steam power was substituted. In 1842, in conjunction with his brother-in-law, the late Mr. Joseph Shuttleworth, he commenced in a small way a general engineering and ironfounding business at Stamp End, where the first large

contract undertaken was to supply pipes for the Boston Water Works at Miningsby. Iron girders for roofs and bridges were also turned out. In 1845 the manufacture of portable engines engaged the firm's attention, and in September of that year they produced their first engine of this class; it was rated as of 8 horse-power, and had a pair of 6-inch cylinders fixed horizontally on the top of the boiler. By 1851 the number of engines made by them in the year had risen to 126, of 611 aggregate horse-power. The result of the Great Exhibition in that year was a material advance in the application of machinery to agriculture. In 1852 they took for the first time the Royal Agricultural Society's first prize for portable engines at the Gloucester show. During 1874 the number of engines delivered was 960; and at the end of 1890 the total number turned out from the commencement, forty-five years ago, amounted to more than 26,200. During the same period also more than 24,150 thrashing machines were turned out, besides corn mills, circular-saw benches, straw-elevators, and other machines. In 1857 a branch establishment was started in Vienna, employing now 700 hands in the manufacture and repair of agricultural machinery suitable to the requirements of Austria, Hungary, and the Danubian principalities. Subsequently other branches were also established in those countries. After the death of Mr. Shuttleworth in 1883 (Proceedings 1884, page 69), the business of the firm was carried on by Mr. Clayton in conjunction with his two nephews; and at the present time the Stamp End Works find employment for between 1,400 and 1,500 hands. On his invitation the works were visited by the Members of this Institution in an excursion from Nottingham on 6th August 1870; and again on 4th August 1885, on the occasion of the Lincoln Meeting of the Institution (Proceedings 1885, pages 434 and 437–440). He was a Justice of the Peace for the city of Lincoln, and also for the Lindsey division of the county, and a Deputy Lieutenant of Lincolnshire; and in 1881 he filled the office of High Sheriff of the county. His death took place while attending morning service in St. Peter-at-Arches church in Lincoln on Sunday, 21st December 1890, in the eightieth year of his age. He became a Member of this Institution in 1870.

Richard Hodson was born in Dudley on 19th January 1831, and was educated at the Grammar School in Leamington. After serving his apprenticeship with Messrs. Simpson and Co., London, he joined the Thames Iron Works, Blackwall, and remained in their employ until his death, a period of twenty-seven years. Amongst the works on which he was engaged in this connection were:—the roof over the Westminster Aquarium, the new Blackfriars railway bridge, and the erection of gates for the Albert Dock, London, for the Barry Dock, Cardiff, and for Penzance Dock; also the turret on the Admiralty Pier, Dover, and other works of less importance. He died on 22nd July 1890, at the age of fifty-nine. He became a Member of this Institution in 1882.

Joseph Taylor was born on 22nd December 1814, at Blanchland, Northumberland. At the age of thirteen he commenced to work in the Derwent lead mines. Two years afterwards he went to serve his apprenticeship in an engineering works at Hexham; and subsequently worked for a short time at the Bedlington Iron Works. In 1838 he went to Birmingham, where he obtained a situation at the London Works of Messrs. Fox Henderson and Co., and then at the Horseley Iron Works, Tipton. About 1842 he started in business as an engineer in Birmingham, and being successful he then occupied larger premises in Broad Street. Having constructed some coining machines for Mr. Ralph Heaton, the founder of the firm of Ralph Heaton and Sons, he was entrusted in 1853 with the order for a complete set of minting machinery for the branch of the Royal Mint at Sydney, New South Wales; and he succeeded in introducing notable improvements in the various machines. In May 1855 it was reported by Captain Ward, R.E., who had the superintendence of the Sydney Mint, that the machinery was perfect both in workmanship and materials. In 1857 he made the bombs which were thrown by Orsini and others at the Emperor Napoleon in Paris. In 1860 he purchased the site of the old works of Messrs. Jennens and Betteridge, papier-maché makers in Constitution Hill, Birmingham, which had been destroyed by fire, and erected the works known as the Derwent Foundry. Here he constructed the

machinery for a branch of the Royal Mint at Melbourne, Victoria; which was sent out in 1869, and has been successfully working ever since. He also made minting machinery for the Siamese government and for several native princes of India; and also machines for several of the European mints. He introduced improvements in rolls for rolling gun barrels; and also in machinery for the manufacture of tubes and many other articles made so extensively in Birmingham and the surrounding district. In 1869 he completed the first hydraulic machine for making moulded pellets of gunpowder, from the designs of Mr. (afterwards Sir) John Anderson, superintendent of machinery, Woolwich Arsenal. This machine was erected at the Royal Gunpowder Factory, Waltham Abbey, and 400 pellets of gunpowder were compressed at each stroke. On 1st January 1873 his son, Mr. Joseph S. Taylor, and Mr. S. W. Challen, who had served an apprenticeship to him, joined him in partnership; and at midsummer 1875 he retired from the firm until 1889, when the business was formed into a private company of which he was appointed chairman. He was one of the trustees of the Yardley charity estates, and took an active part in the public life of the parish in which he resided. His death took place at his residence at Acocks Green, near Birmingham, on 2nd November 1890, at the age of seventy-five. He became a Member of this Institution in 1867.

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TUBE-FRAME RAILWAY WAGONS.

Low-sided Gondola Wagon with Drop Ends.

Fig. 1. *Plan.*

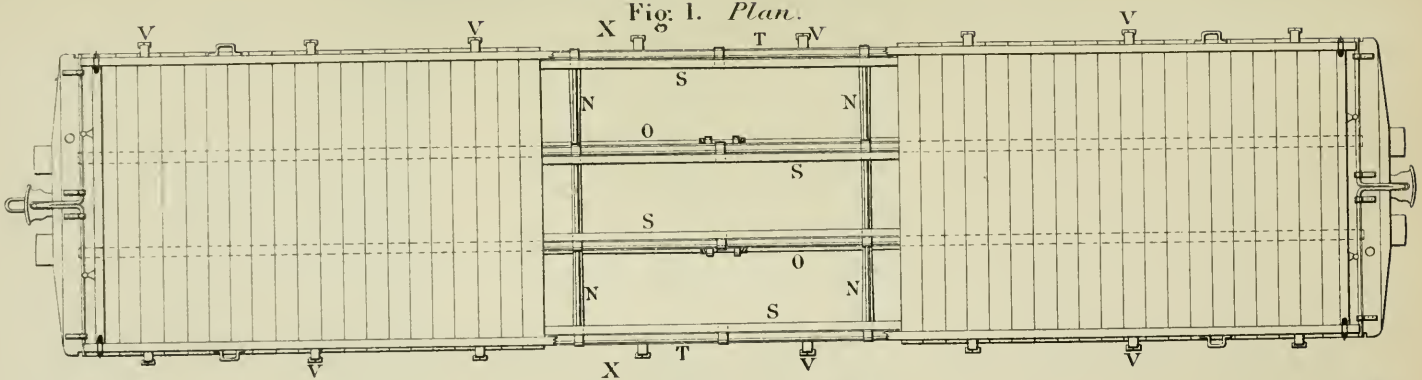
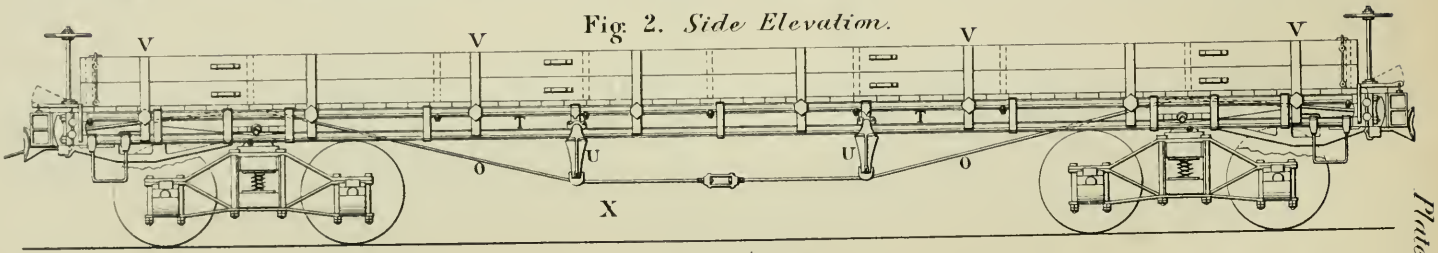


Fig. 2. *Side Elevation.*



(*Mechanical Engineers 1890*)

Scale 1/60th

Inches 12 0 5 10 15 20 25 30 Feet.

Plate 137.

Fig. 3. *Plan of Frame End.*

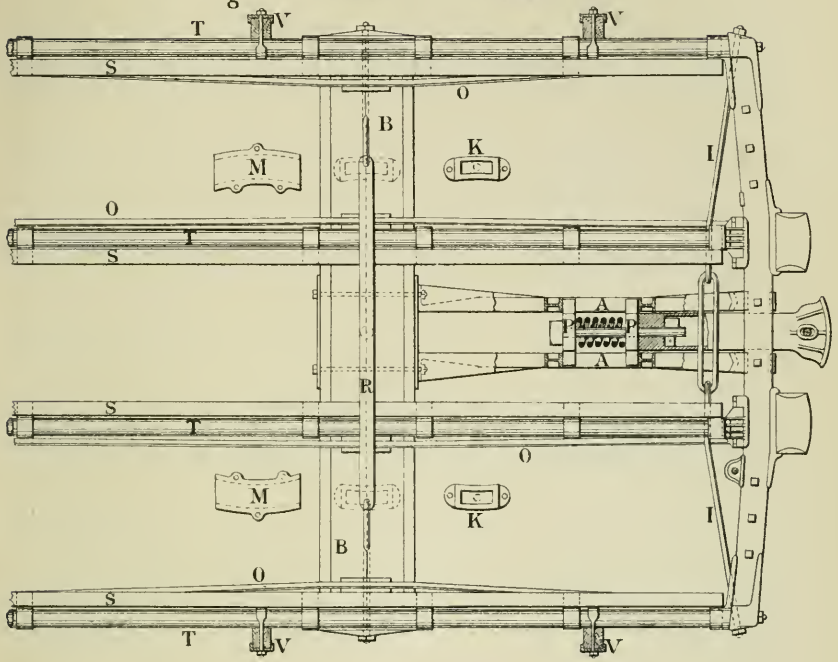
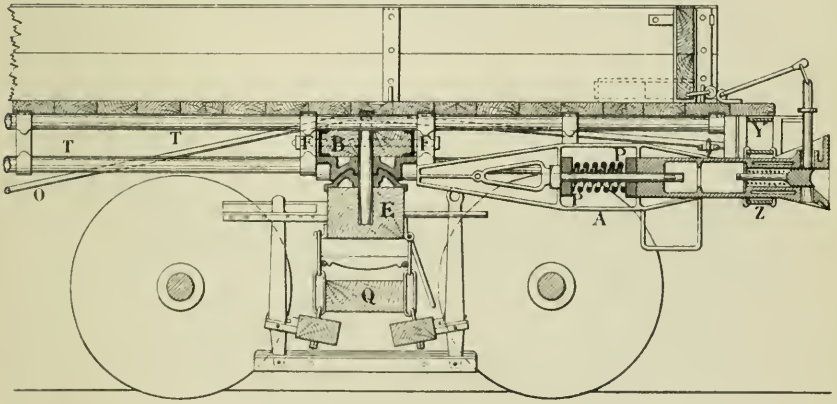


Fig. 4. *Longitudinal Section of Wagon End.*



(Mechanical Engineers 1890) *Scale* $\frac{1}{30}^{th}$

inches 12 6 0 1 2 3 4 5 6 7 8 Feet.

Fig. 5. *Transverse Section of Wagon Body at XX Plate 137.*

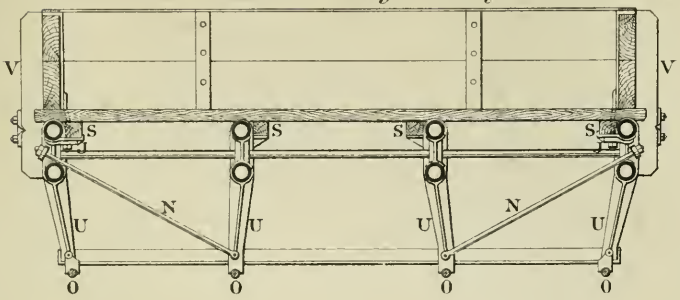


Fig. 6. *End Elevation of Wagon Body.*

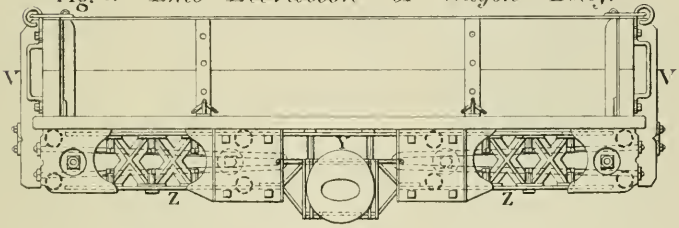


Fig. 7. *End Elevation with Headstock bared.*

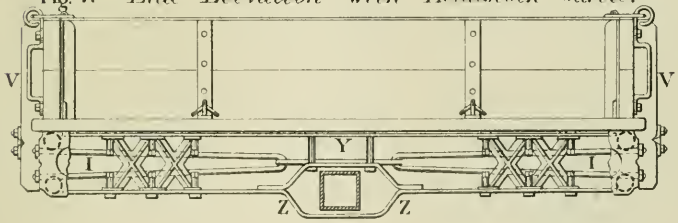
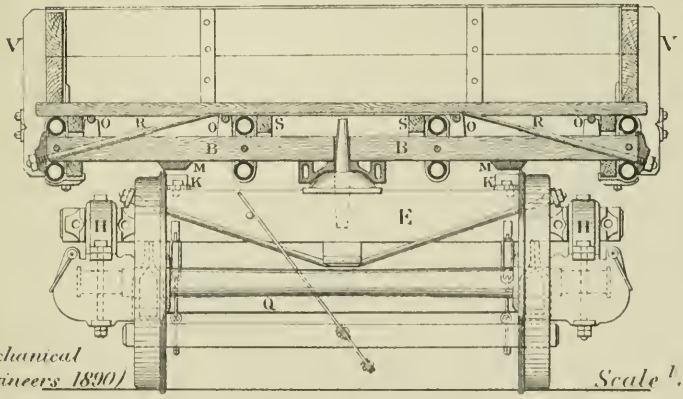


Fig. 8. *Transverse Section of Wagon Body on Bogie Truck.*



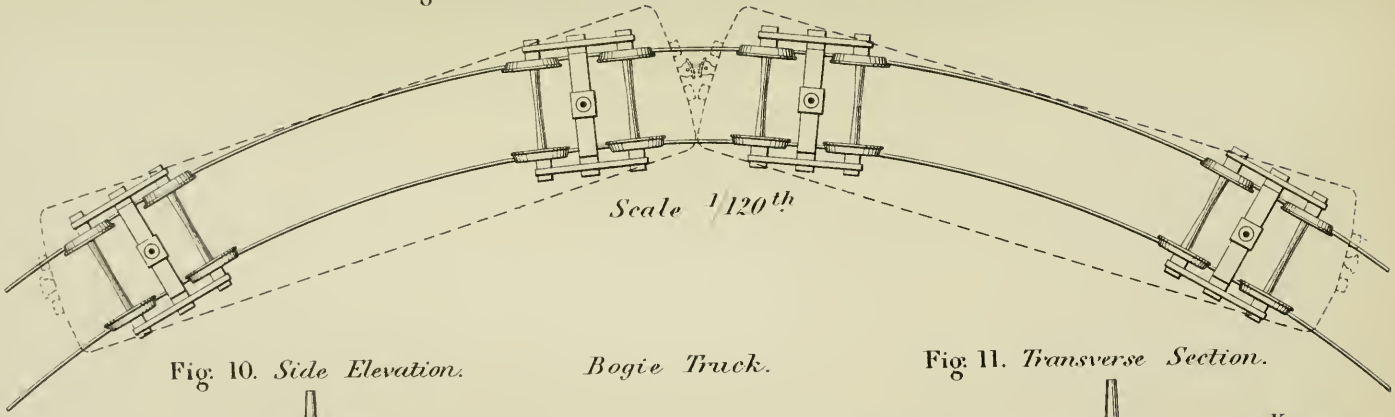
(*Mechanical Engineers 1890*)

Scale 1/30th

ins. 12 6 0 1 2 3 4 5 6 7 8 Feet.

TUBE-FRAME RAILWAY WAGONS.

Fig. 9. *Rounding curve of 55 feet radius.*

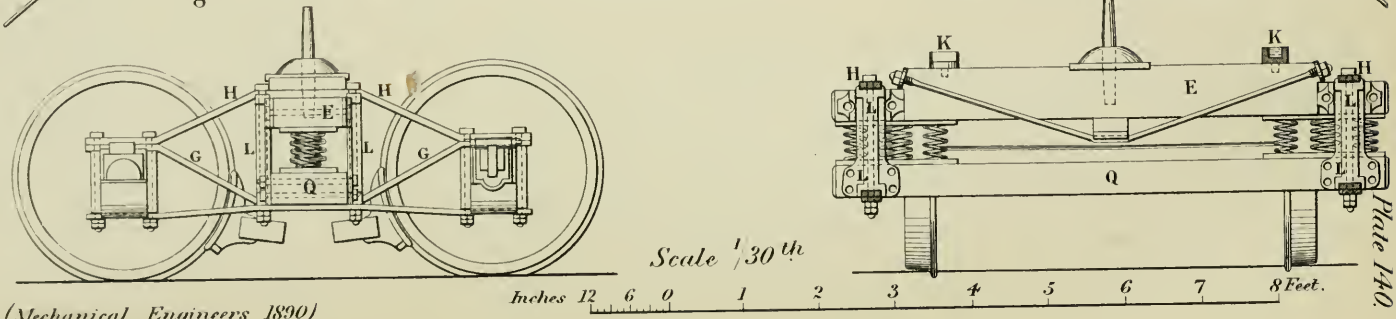


Scale 1/120th

Fig. 10. *Side Elevation.*

Bogie Truck.

Fig. 11. *Transverse Section.*



Scale 1/30th

Inches 12 6 0 1 2 3 4 5 6 7 8 Feet.

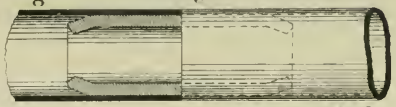
(Mechanical Engineers 1890)

Plate 140.

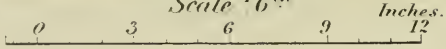
TUBE-FRAME RAILWAY WAGONS.

Plate 141.

Fig. 12. *Jointing of Tubes.*



Scale 1/6th



Hexagonal Plug.

Fig. 13. *Fastening of Headstock to Tubes.*

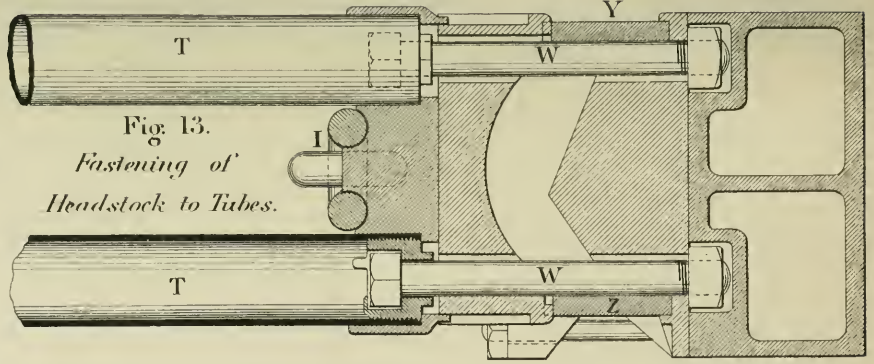


Fig. 14.

Fig. 15.

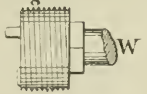
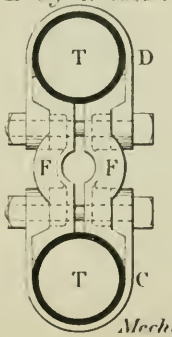


Fig. 16.

Scale 1/6th

Fig. 18. *Clips at Body Bolster.*



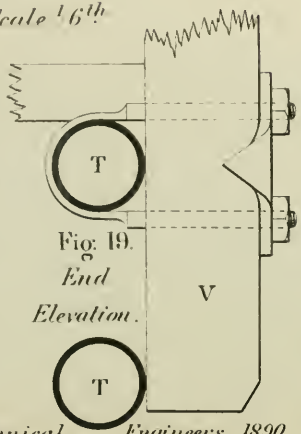
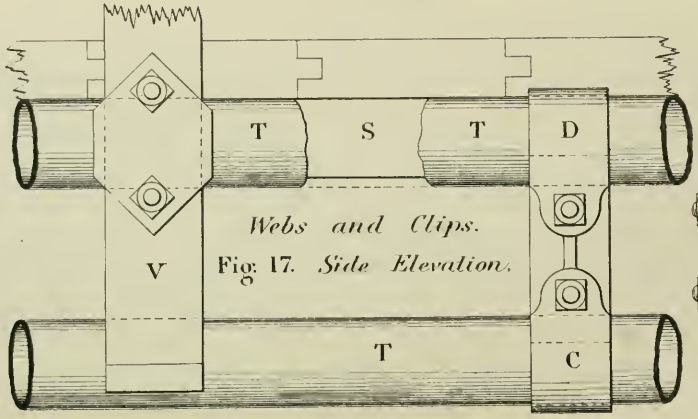


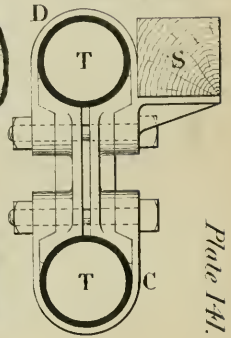
Fig. 19. *End Elevation.*



Webs and Clips.

Fig. 17. *Side Elevation.*

Fig. 20. *End Elevation.*



Mechanical Engineers 1890

Plate 141.

Low-sided Gondola Wagon with Drop Ends.

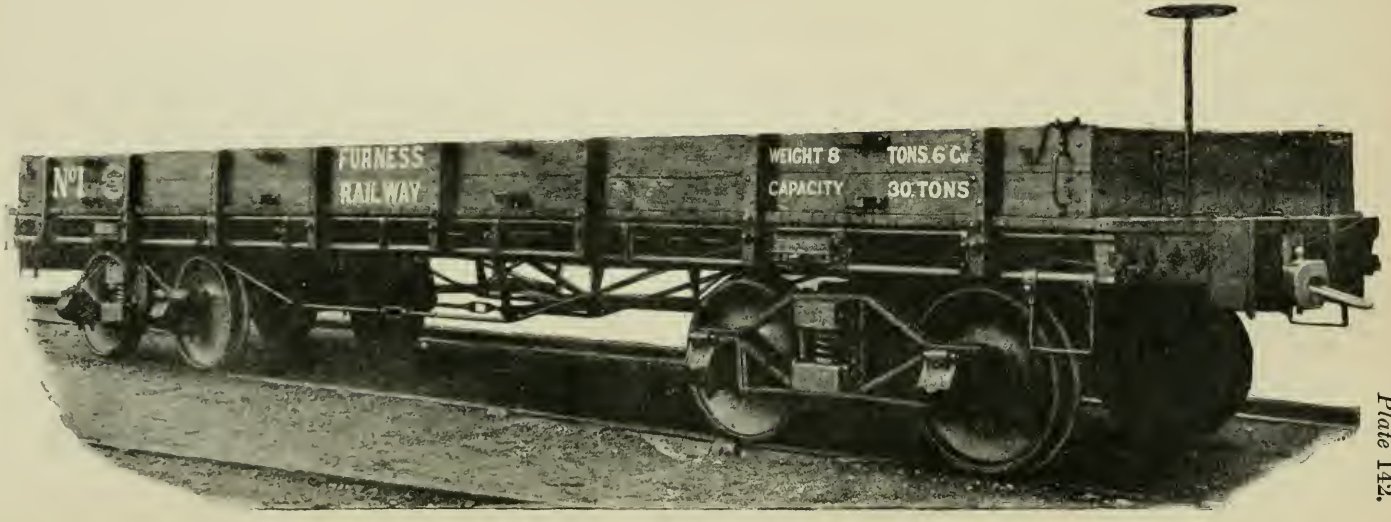


Plate 142.

High-sided Gondola Wagon, built with or without Drop Side Doors.

Plate 143.

Hopper-Bottom Coal Wagon.

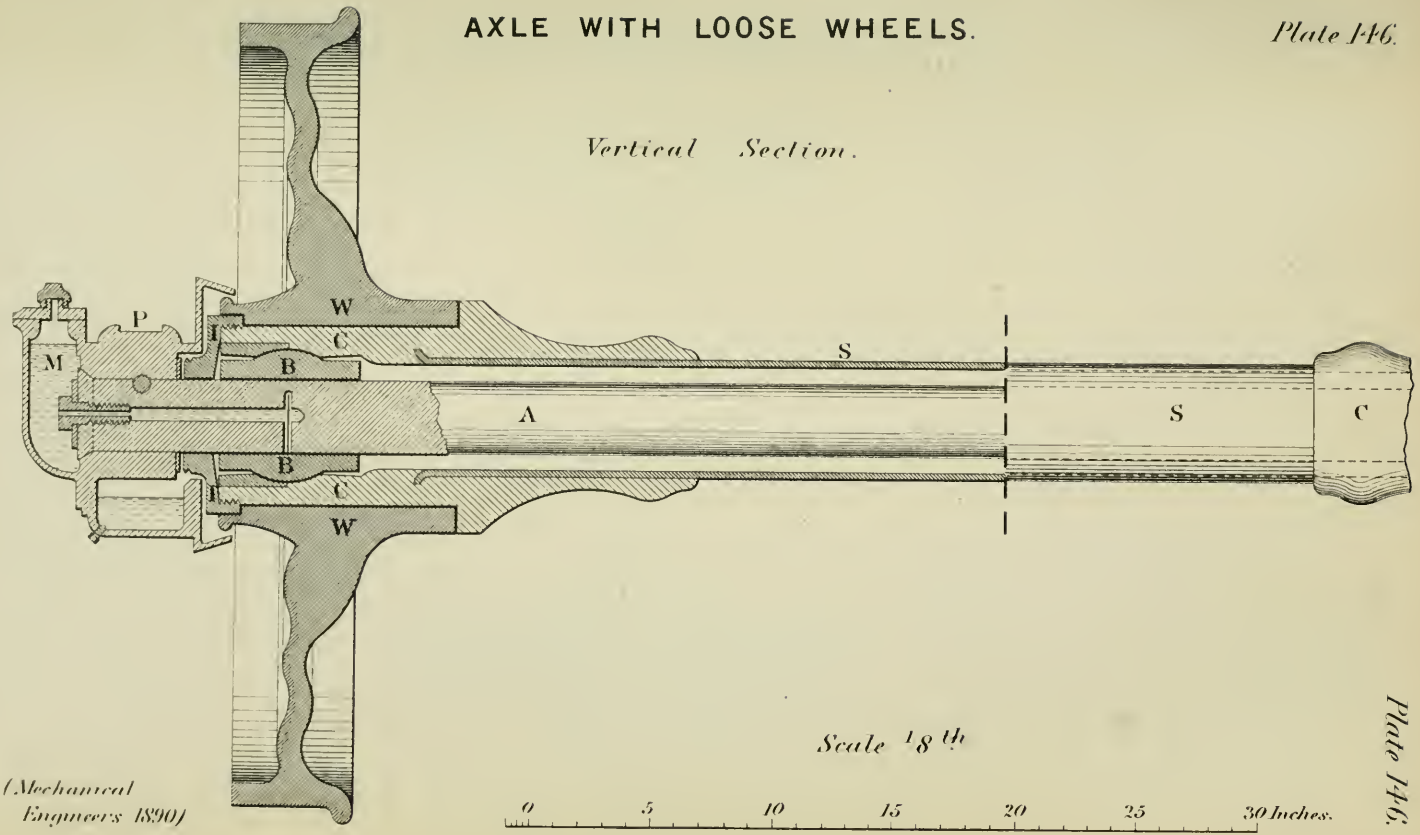
Plate 144.

Ventilated Wagon for general purposes.

Plate 145.

AXLE WITH LOOSE WHEELS.

Vertical Section.



Scale 1/8 th

0 5 10 15 20 25 30 Inches.

(Mechanical Engineers 1890)

Plate 146.

MILLING CUTTERS.

Plate 147.

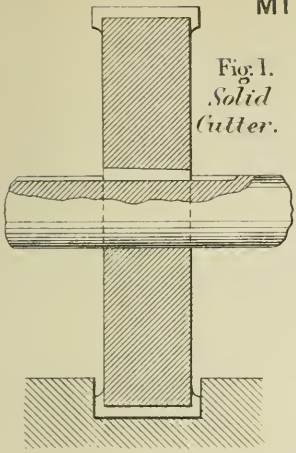


Fig. 1.
Solid Cutter.

Scale 1/4th

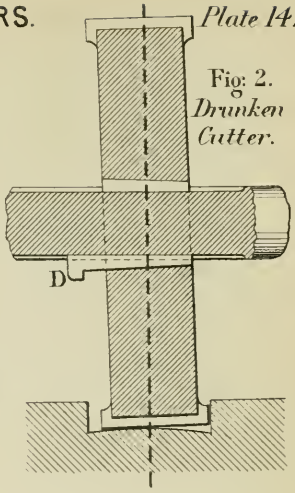


Fig. 2.
Drunken Cutter.

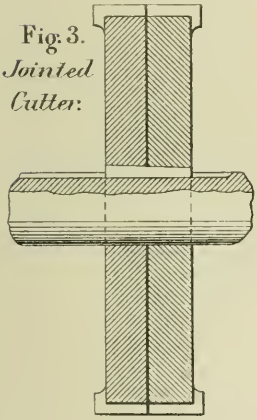


Fig. 3.
Jointed Cutter.

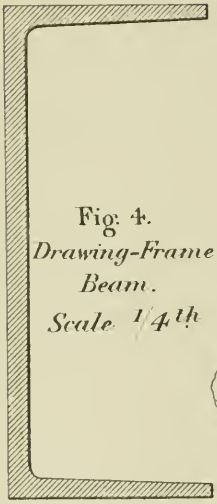


Fig. 4.
Drawing-Frame Beam.
Scale 1/4th

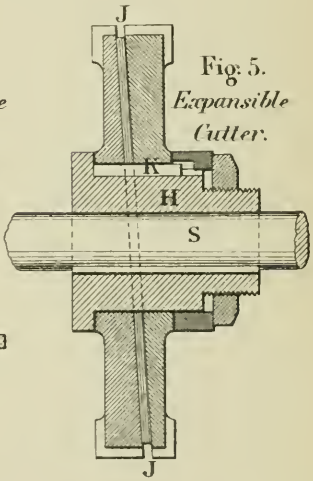
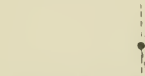


Fig. 5.
Expansible Cutter.



Backed-off Cutter.

Fig. 6.

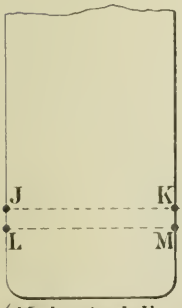


Fig. 7.

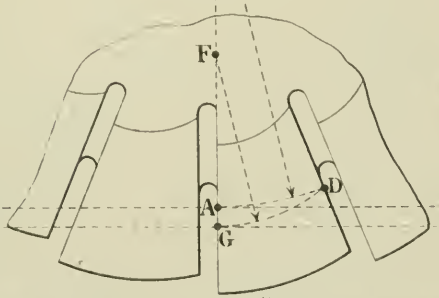
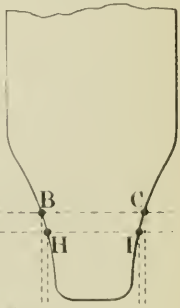


Fig. 8.



(Mechanical Engineers 1890)

Scale full size.

Expansible Cutters.

Fig. 9.

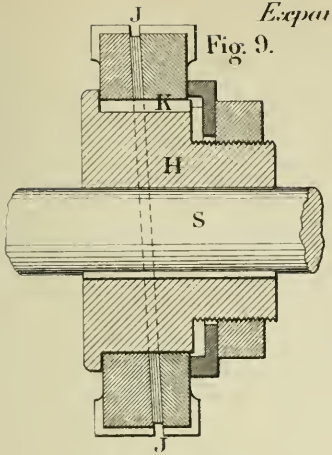


Fig. 10.

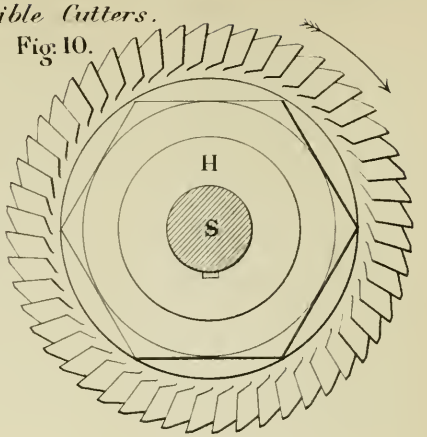


Fig. 11.

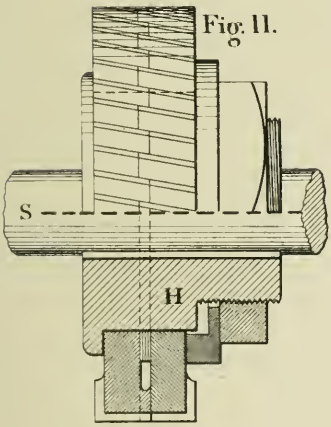


Fig. 12.

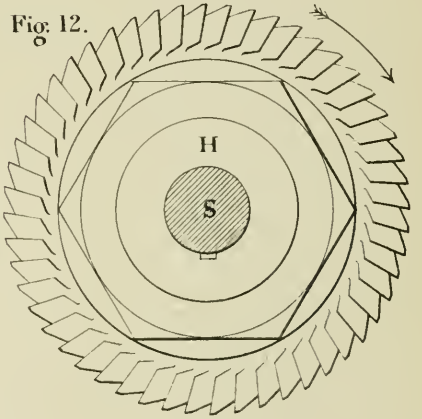


Fig. 13.

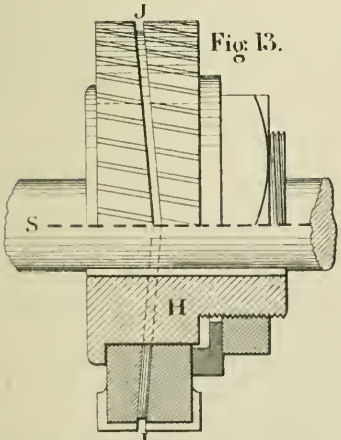
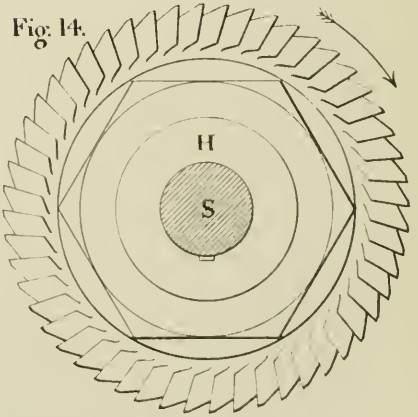


Fig. 14.



(Mechanical Engineers 1890) *Scale 1/4 th*

0 1 2 3 4 5 6 7 8 9 10 Inches.

Form of Teeth. Fig. 15. *Plan.*

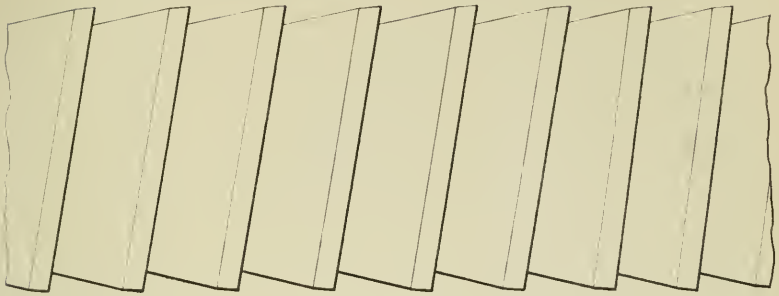
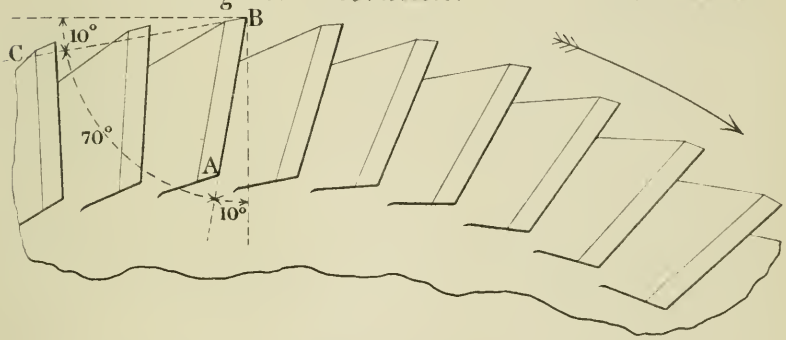


Fig. 16. *Elevation.* *Full size.*



Comparison with Planing Tool.

Fig. 17.

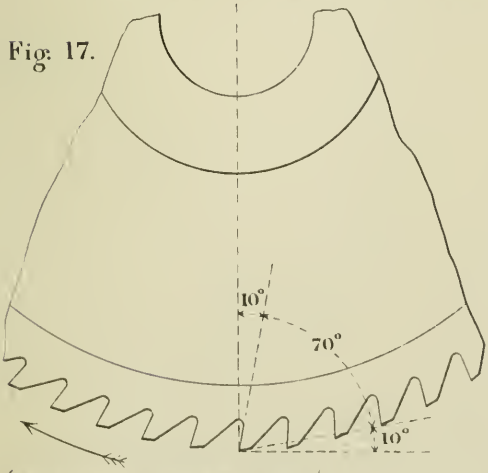
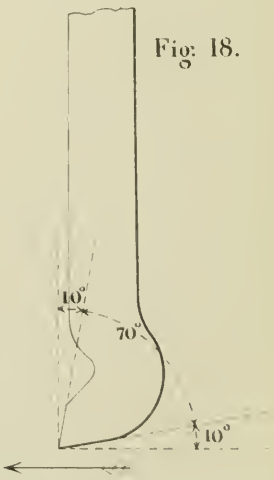


Fig. 18.

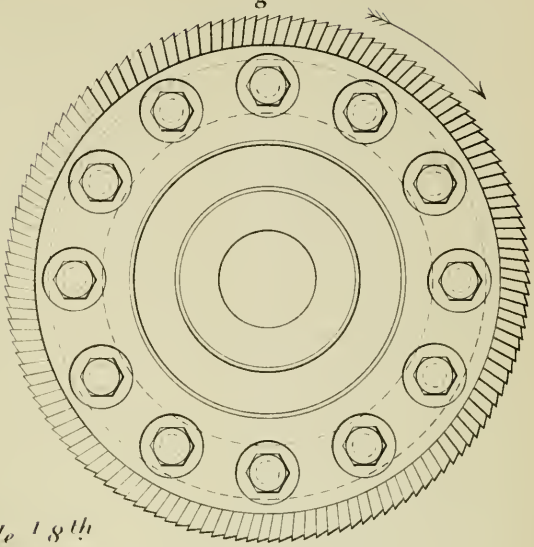


(Mechanical Engineers 1890)

Expansible Cutter.

Fig. 19.

Fig. 20.



Scale 1 8th

Built-up Cutter.

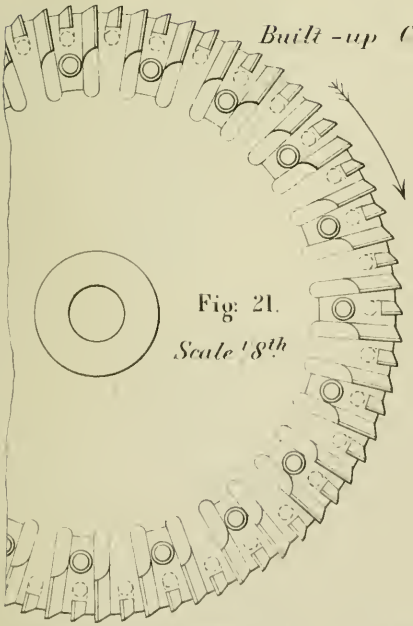
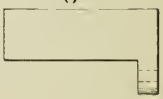


Fig. 21.

Scale 1 8th

Fig. 22.

Fig. 23.



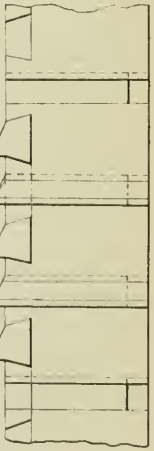


Fig. 24.

Scale 1 4th

(Mechanical Engineer's 1890) *Scale 1 8th*

0 5 10 15 20 Inches.

MILLING CUTTERS. *Plate 151.*

Two Cutters on one spindle.

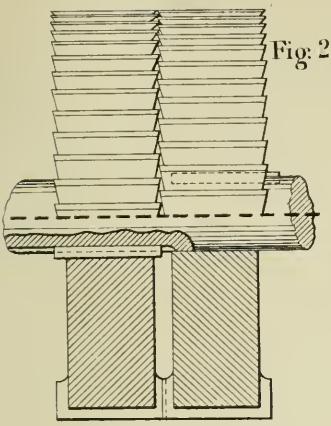


Fig. 25.

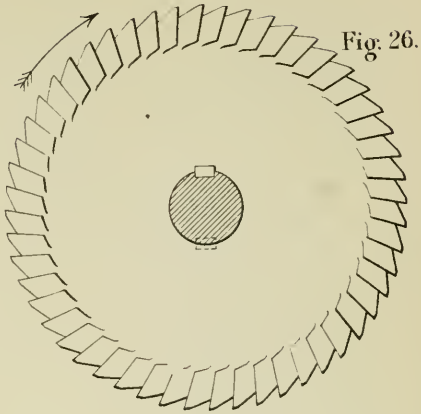


Fig. 26.

Two-diameter Cutter.

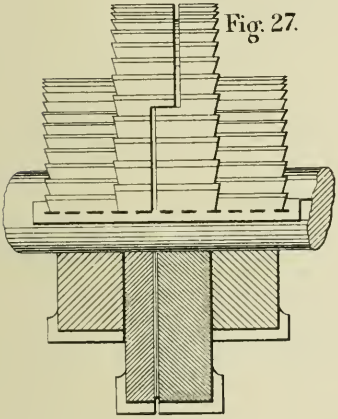


Fig. 27.

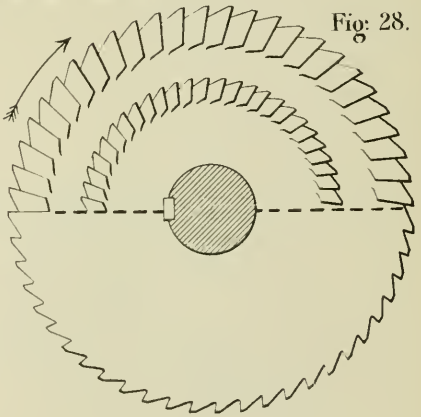


Fig. 28.

Concave Cutter.

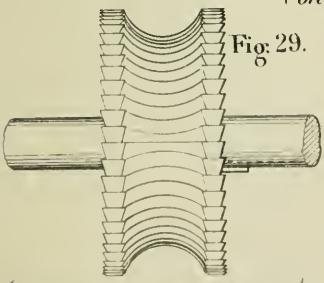


Fig. 29.

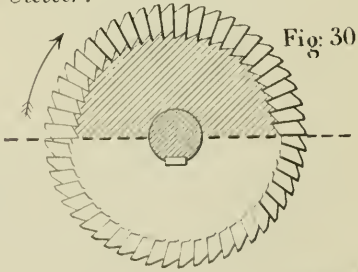


Fig. 30.

(Mechanical Engineers 1890)

Scale 1/4th

0 1 2 3 4 5 6 7 8 9 10 Inches.

Milling Machine for Mule Headstock.

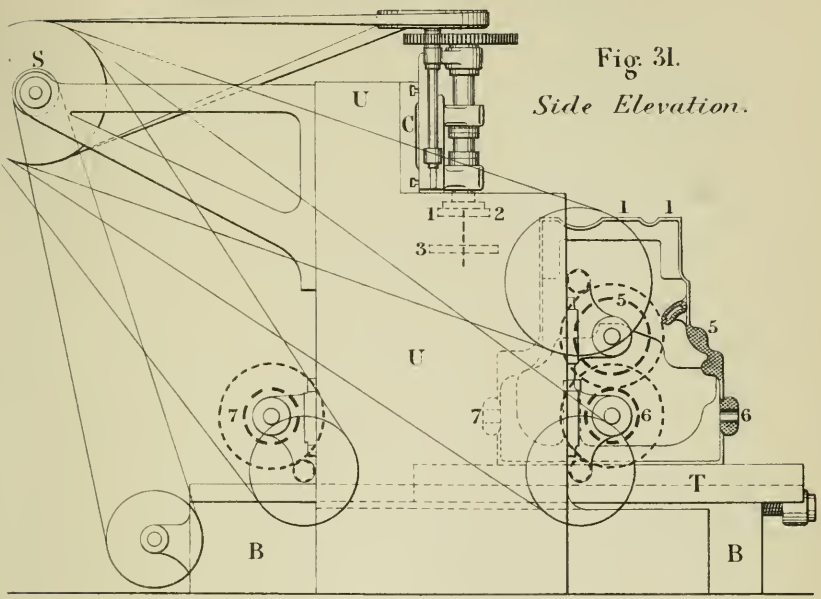


Fig. 31.
Side Elevation.

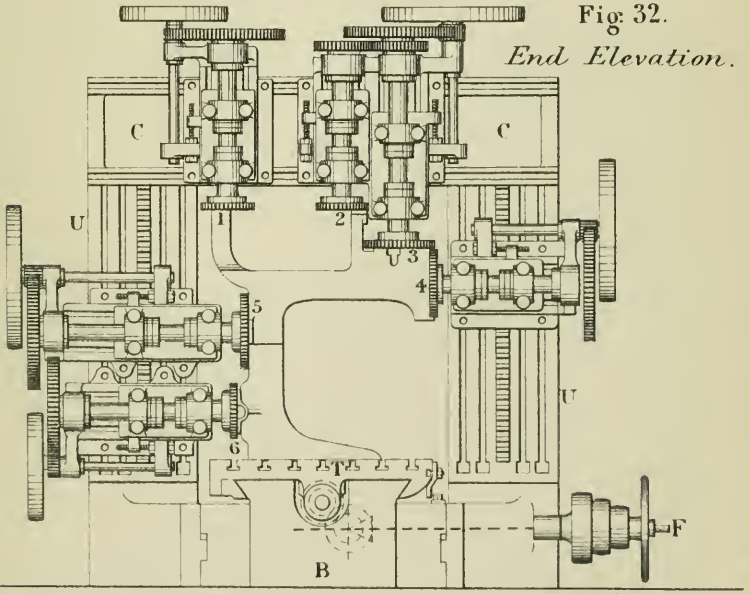


Fig. 32.
End Elevation.

(Mechanical Engineers 1890) *Scale 1/32nd*

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 Feet.

Milling Machine for Mule Headstock.

Fig. 33. *Plan.*

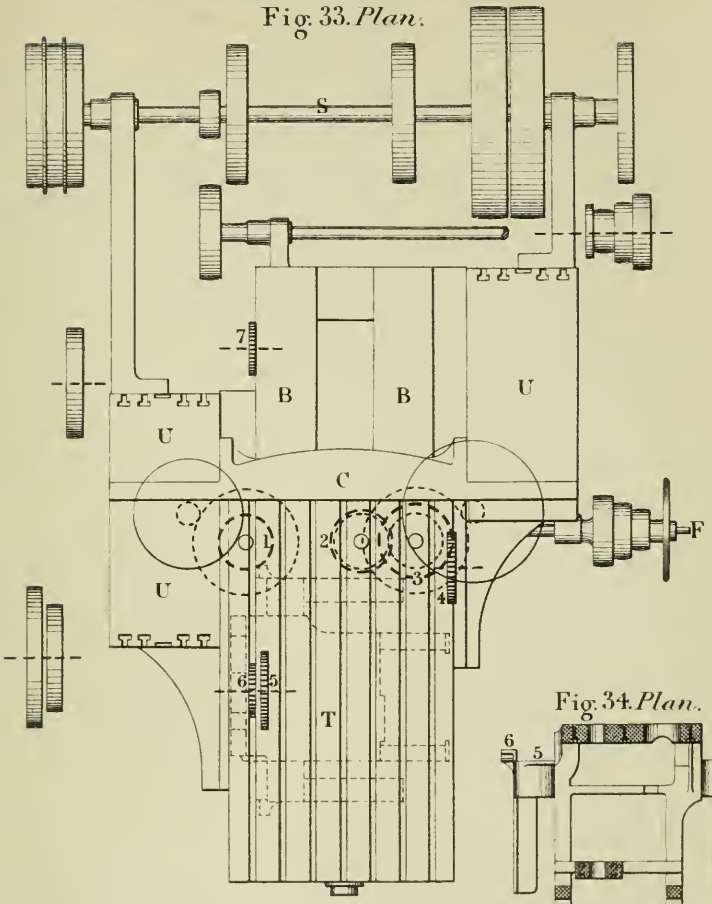
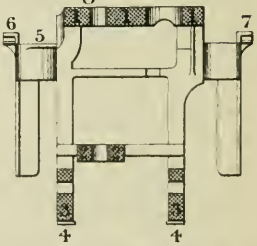


Fig. 34. *Plan.*



Mule Headstock.

Fig. 37. *Back Elevation.*

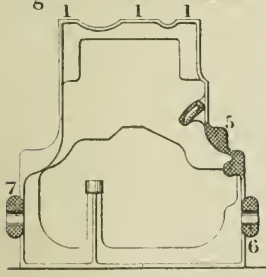


Fig. 36. *Side Elevation.*

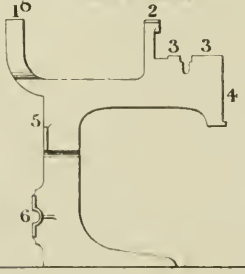
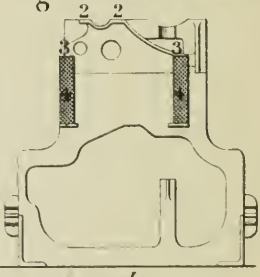


Fig. 35. *Front Elevation.*



(Mechanical Engineers 1890) *Scale 1/32nd*

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 Feet.

Milling Discs for Crank-axle Webs.

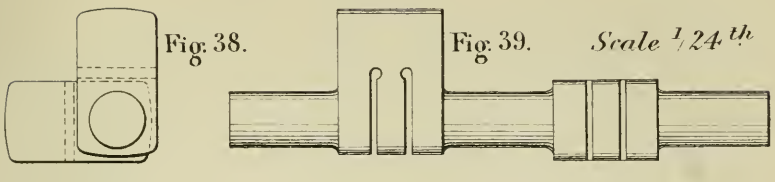


Fig. 40. *Elevation of Disc.*

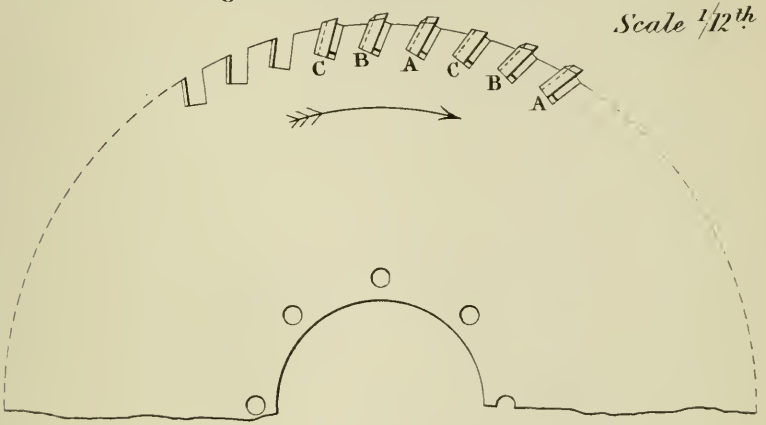


Fig. 41. *Plan of Rim.*

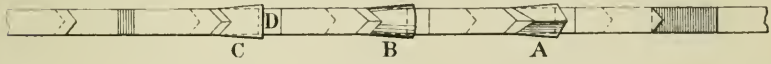
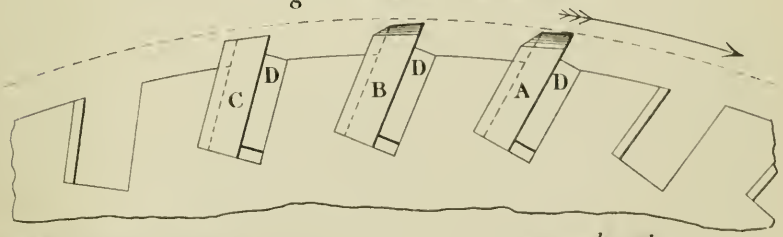


Fig. 42. *Elevation.*



(Mechanical Engineers 1890)

Scale 1/4th

0 1 2 3 4 5 6 7 8 9 10 Inches.

Set of Cutters in Milling Discs for Crank-axle Webs.

Fig. 43.

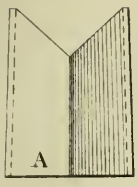
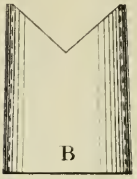


Fig. 45.



Scale full size.

Fig. 47.

Fig. 44.

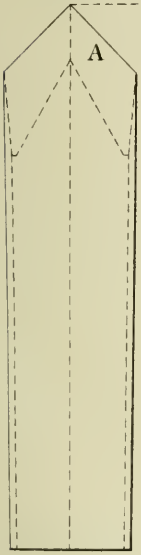
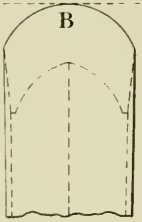


Fig. 46.



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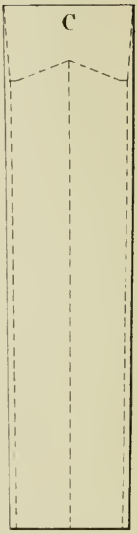


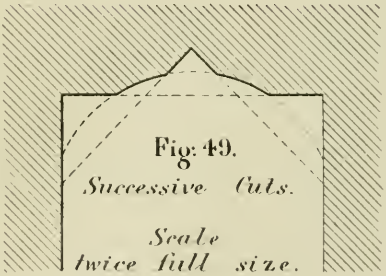


Fig. 49.

Successive Cuts.

Scale twice full size.

Fig. 50.

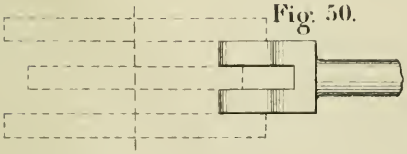


Fig. 51.

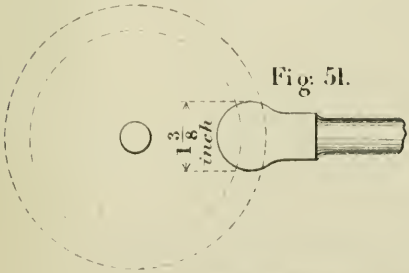
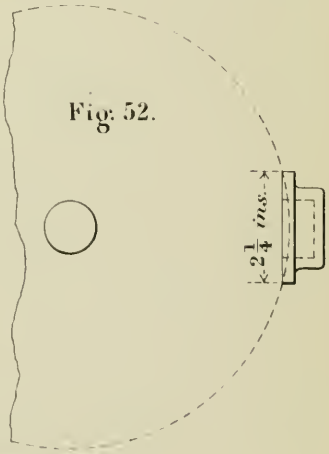


Fig. 52.



(Mechanical Engineers 1890)

Cutters with separate inserted blades.

Fig: 53.

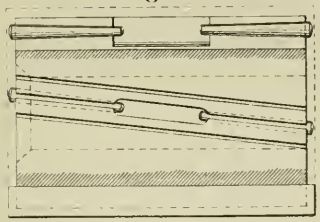
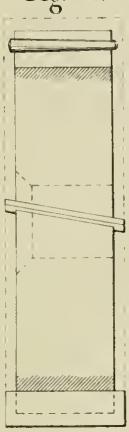


Fig: 54.

Fig: 59.
Flat Blade
1/8 inch thick.

Full size.

Fig: 55.



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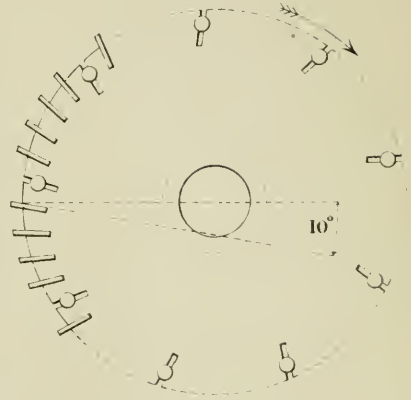

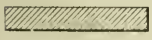

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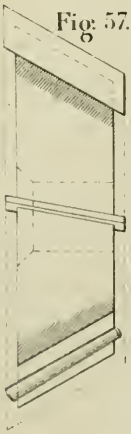

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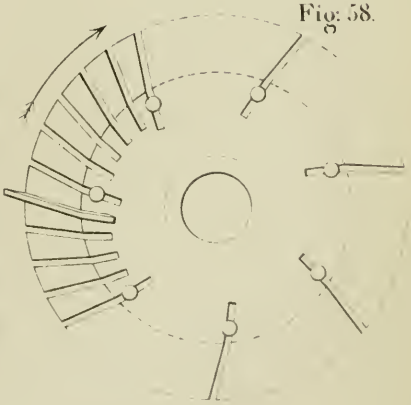

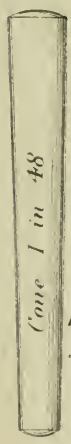

Fig: 60.

Taper Pin.

Full size.

(Mechanical Engineers 1890) *Scale 1/4th*

TJ
1
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1890

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